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THE CALCULATION of HORSE POWER MADE EASY

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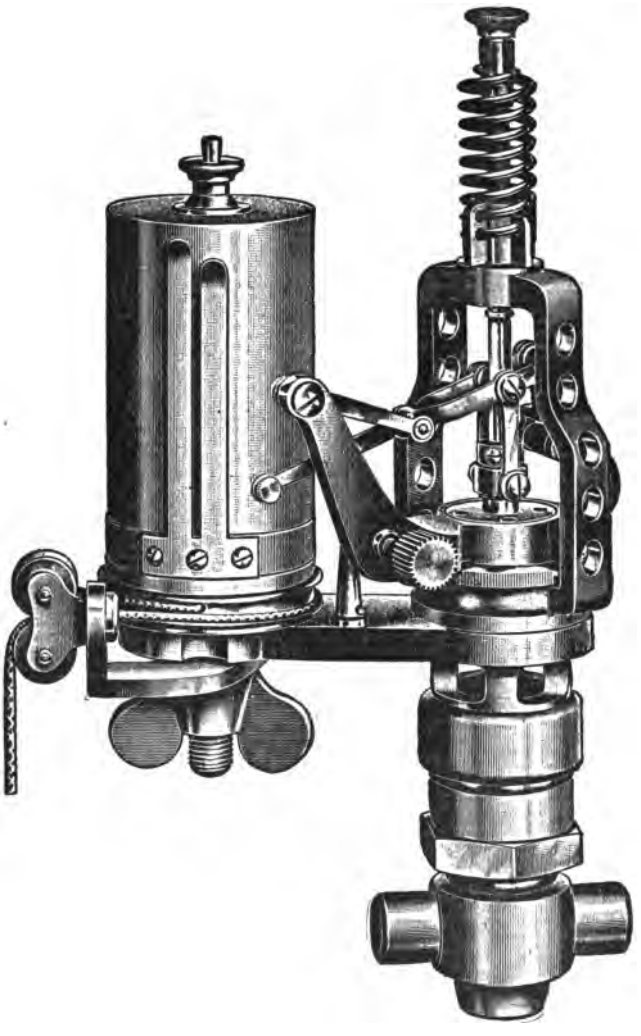

THOMPSON INDICATOR "1905" Pattern.
With External (Tension) Spring.

The Calculation of Horsepower Made Easy

A MANUAL OF SIMPLE AND NON-TECHNICAL INFORMATION FOR THE USE OF ENGINEERS, MACHINISTS, STUDENTS AND DESIGNERS. GIVING FULL INFORMATION WITH REGARD TO THE CALCULATION OF THE HORSEPOWER OF STEAM ENGINES, AND EXPLOSIVE AND ELECTRIC MOTORS. CONTAINING NUMEROUS TABLES, USEFUL RULES AND FORMULAS

Illustrated.

BY

L. ELLIOTT BROOKES

AUTHOR OF "THE AUTOMOBILE HAND-BOOK," "PRACTICAL GAS AND OIL ENGINE HAND-BOOK," ETC., ETC.

CHICAGO

FREDERICK J. DRAKE & CO., Publisher

1905

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PREFACE

It has been the endeavor in this book to deal in as practical and non-technical manner as possible with the calculation of the power of Steam, Gas, Gasoline, Oil Engines and Electric Motors.

Particular attention has also been given to the explanation of the elementary principles upon which these calculations are based.

Rules for plotting engine diagrams by geometrical, arithmetical and graphical are given and also fully explained.

A number of useful rules, formulas and tables are also presented in as simple a manner as possible, that will be found of untold value to **Engineers, Machinists** and **Designers** in the calculation of horsepower.

THE AUTHOR.

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The Calculation of Horsepower Made Easy

ENERGY

A standard horsepower is the amount of energy that will raise a weight of 33,000 pounds one foot high in a minute, or 550 pounds one foot high in one second. An engine or motor exerting one actual horsepower will raise a weight of 10 pounds 3,300 feet in one minute, but will require 10 minutes to raise 330,000 pounds one foot high.

The heat energy of fuel is measured theoretically on the following basis: If a pound weight fall 780 feet in a perfect vacuum it would generate heat energy sufficient to raise the temperature of one pound of water, one degree Fahrenheit. The heat energy required to convert one pound of water at a temperature of 32 degrees Fahrenheit into steam at atmospheric pressure, would lift a weight of 2,000 pounds 400 feet high in one minute, or develop two-fifths of one horsepower for one hour.

ANIMAL POWER

A horse can exert a full horsepower hour for only six hours a day. One mechanical horsepower is therefore equivalent to the work of four horses.

The average work of a good horse may be rated at 22,500 pounds raised one foot high in a minute for eight hours a

day. A draft-horse can draw a load of 1,600 pounds 25 miles per day on a good road, weight of the vehicle included.

A man can exert a force of 30 pounds for 10 hours a day, which is equivalent to 4,500 pounds raised one foot high in a minute, or two-fifths the work of a horse.

A man can travel, without a load, on the level, for 8½ hours a day, at the rate of 3½ miles an hour, or 30 miles a day.

A man carrying a load a short distance and returning unloaded, can carry 135 pounds, 7 miles a day. A man can transport in a wheelbarrow, 150 pounds, 10 miles a day.

HORSEPOWER

Horsepower is of three kinds: calculated, actual or brake, and indicated horsepower. Calculated horsepower is always greatly in excess of actual or brake horsepower, as heat and friction losses do not enter into consideration in the formulas used.

Actual or Brake horsepower is obtained by the use of a Prony brake, so called after its inventor. This simple device gives the actual energy in foot-pounds per minute, delivered at the driving shaft.

Indicated horsepower represents the actual thermo-dynamic (heat pressure) conditions within the engine cylinder, but does not take into account friction or other external power losses.

CALCULATED HORSEPOWER

The factors entering into the calculation of the horsepower of a steam engine or an explosive motor are, the effective temperature of the charge in the cylinder as indicated by the average pressure throughout the piston stroke, the cubic contents of the cylinder, which are given by the length of the stroke and the area of the piston, and the number of working strokes or impulses per minute.

The product of these factors, which is found by multiplying them together, will give the available energy in foot-pounds per minute. This product, divided by 33,000, gives the horsepower required.

To ascertain the horsepower when the average pressure upon the piston in pounds per square inch is known:

Find the area of the piston in square inches, by multiplying the square of its diameter by 0.7854.

Find the total pressure in pounds on the piston by multiplying the area by the average effective pressure in pounds per square inch. The average effective pressure is the average pressure in pounds per square inch less 14.7, which must be deducted to allow for the atmospheric pressure against the piston.

Find the useful piston travel in feet per minute by multiplying twice the length of the piston stroke in feet by the number of revolutions per minute of the crank shaft, for a double-acting steam engine, or by the number of working impulses per minute for an explosive motor. Find the energy in foot pounds per minute by multiplying the total pressure in pounds on the piston by the useful piston travel in feet per minute.

TABLE NO. 1

Average Steam Pressure on Piston, in Pounds per Square Inch

Average Pressure throughout the Piston Stroke. Initial Pressure =1.		.966	.937	.919	.846	.743	.699	.596	.385
Number of Volumes to which the Steam is Expanded.		$1\frac{1}{3}$	$1\frac{1}{2}$	$1\frac{3}{5}$	2	$2\frac{2}{3}$	3	4	8
Point of Cut-off.		$\frac{3}{4}$	$\frac{2}{3}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{8}$
Initial Pressure in Pounds per Square Inch.	50	48.2	46.7	45.9	42.3	37.1	35.0	29.8	19.2
	55	53.0	51.3	50.5	46.6	40.8	38.4	32.8	21.2
	60	57.8	56.0	55.1	50.8	44.5	41.9	35.8	23.1
	65	62.8	60.7	59.7	55.0	48.2	45.4	38.8	24.9
	70	67.5	65.3	64.3	59.2	52.4	48.9	41.6	26.7
	75	72.3	70.0	68.9	63.5	56.1	52.4	44.7	28.6
	80	77.1	75.7	73.5	67.7	59.3	55.9	47.7	30.8
	85	81.9	80.3	78.1	72.0	63.0	59.4	50.7	32.7
	90	86.7	84.0	82.7	76.2	66.8	62.9	53.7	34.6
	95	91.5	88.7	87.3	80.4	70.4	66.4	56.7	36.6
	100	96.4	93.3	91.9	84.6	74.2	69.9	59.6	38.5
	105	101.2	98.0	96.5	88.9	77.9	73.4	62.6	40.4
	110	106.0	101.7	101.0	93.1	81.6	76.9	66.6	42.3
	115	110.8	106.3	105.6	97.4	85.2	80.4	69.6	44.2
	120	115.6	112.0	110.2	101.6	89.0	83.9	71.6	46.2
	125	120.5	115.7	114.8	105.8	102.8	87.4	74.6	48.1
		1	2	3	4	5	6	7	8

TABLE No. 1—CONT.

Average Steam Pressure on Piston, in Pounds per Square Inch

Average Pressure throughout the Piston Stroke. Initial Pressure =1.		.966	.937	.919	.846	.743	.699	.596	.385
Number of Volumes to which the Steam is Expanded.		$1\frac{1}{3}$	$1\frac{1}{2}$	$1\frac{3}{5}$	2	$2\frac{2}{3}$	3	4	8
Point of Cut-off.		$\frac{3}{4}$	$\frac{2}{3}$	$\frac{5}{8}$	$\frac{1}{2}$	$\frac{3}{8}$	$\frac{1}{3}$	$\frac{1}{4}$	$\frac{1}{8}$
Initial Pressure in Pounds per Square Inch.	130	125.3	121.3	119.4	110.0	96.4	90.9	77.5	59.8
	140	134.9	130.7	128.6	118.5	103.8	97.9	85 3	53.9
	150	144.6	139.3	137.8	126.5	111.3	104.9	89.5	57.7
	160	154.2	151.3	147.0	135.4	118.7	111.8	95.4	61.6
	170	163.8	160.7	156.2	143.9	126.1	118.8	101.4	65.4
	180	173.5	168.0	165.4	152.4	133.5	125.8	107.4	69.3
	190	183.1	177.3	174.5	160.8	140.9	132.8	113.3	73.1
	200	192.8	186.7	183.8	169.3	148.4	139.0	119.3	77.0
	210	202.4	195.0	192.9	177.8	154.8	146.8	125.3	80.8
	220	212.0	203.3	202.1	186.2	163.2	153.8	133.2	84.6
	230	221.6	212.7	211.3	194.7	170.4	160.8	139.2	98.5
	240	231.3	224.0	220.5	203.2	178.1	167.8	143.2	92.4
	250	240.9	233.3	229.7	211.6	185.4	174.7	149.1	96.2
	260	250.6	242.7	238.9	220.1	192.9	181.8	155.1	99.7
	280	269.8	261.3	257.2	237.0	207.7	195.7	170.6	107.8
	300	289.1	280.0	275.6	254.0	222.5	208.7	179.0	115.5
		1	2	3	4	5	6	7	8

The horsepower may then be ascertained by dividing the energy in foot-pounds per minute by 33,000.

While there are numerous formulas in use for calculating the horsepower of an engine, one of the most simple is as follows:

$$HP = \frac{P \times L \times A \times N}{33{,}000} \qquad (1)$$

Where P is the average effective pressure in pounds per square inch, L twice the length of the piston stroke in feet, A the area of the piston in square inches, N the number of revolutions of the crank shaft per minute and HP the horsepower.

EXAMPLE: What horsepower will a steam engine of 4-inch bore and 6-inch stroke develop at 300 revolutions of the crank shaft per minute, cutting off at one-third stroke and having an initial pressure of 150 pounds per square inch?

ANSWER: The average pressure from Table No. 1, corresponding to 150 pounds initial pressure, with one-third cut-off, is 104.9 pounds. From this must be deducted 14.7 pounds, which represents the back or atmospheric pressure in the case of a single expansion engine, giving 90.2 pounds as the average effective pressure per square inch on the piston. From Table No. 2 the area of a circle 4 inches in diameter is 12.57 square inches, and twice the length of the piston stroke in feet is equal to one foot, then

$$HP = \frac{90.2 \times 1 \times 12.57 \times 300}{33{,}000} = 10.31 \text{ horsepower.}$$

The following formulas, Nos. 2, 3, 4 and 5, are merely transpositions of Formula No. 1, but will be found very useful in ascertaining the value of any one of the five factors in Formula No. 1, when the other four are known.

$$P = 33{,}000 \frac{HP}{L \times A \times N} \qquad (2)$$

Where P is the average effective pressure on the piston in pounds per square inch.

EXAMPLE: What is the average effective pressure on the piston of an engine, with a cylinder 12 inches in diameter and piston stroke of 18 inches, the number of revolutions of the crank shaft being 100 per minute, and the horsepower 40?

ANSWER: As the area corresponding to 12 inches diameter is 113.09, or in round numbers, 113, then by Formula No. 2

$$P = 33{,}000 \frac{40}{3 \times 113 \times 100} = 38.9 \text{ pounds.}$$

To ascertain the required length of the piston stroke in feet, when the other terms in the equation are known:

$$L = 33{,}000 \frac{HP}{P \times A \times N} \qquad (3)$$

Where L is equal to twice the length of the piston stroke in feet.

EXAMPLE: An engine is required to develop 40 horsepower, with 38.9 pounds average effective pressure per square inch on a piston 12 inches in diameter and a speed of the crank shaft of 100 revolutions per minute. What should be the length of the piston stroke?

ANSWER: The average effective pressure being 38.9 pounds, then by Formula No. 3,

$$L = 33{,}000 \frac{40}{38.9 \times 113 \times 100} = 3.0 \text{ feet.}$$

Giving a piston stroke of 18 inches.

To find the required cylinder diameter, other conditions being as before stated:

$$A = 33{,}000 \frac{HP}{P \times L \times N} \qquad (4)$$

Where A is the area of the cylinder in square inches.

EXAMPLE: An engine is required to develop 40 horsepower with an average effective pressure on the piston of 38.9 pounds per square inch. The length of the stroke is 18 inches and the speed of the engine crank shaft is 100 revolutions per minute, what should be the cylinder diameter?

ANSWER: The area of the cylinder by Formula No. 4 is, therefore

$$A = 33{,}000 \frac{40}{38.9 \times 3 \times 100} = 113.1 \text{ square inches.}$$

And from Table No. 2, the nearest diameter corresponding to an area of 113.1 square inches is 12 inches.

The speed of the crank shaft of an engine may be readily ascertained from Formula No. 5, that is, if N be the speed of the crank shaft of the engine in revolutions per minute, then

$$N = 33{,}000 \frac{HP}{P \times L \times A} \qquad (5)$$

EXAMPLE: What should be the speed of the crank shaft of an engine with a cylinder of 12-inch bore and 18-inch piston stroke, to develop 40 horsepower with an average effective pressure of 38.9 pounds per square inch on the piston?

ANSWER: The speed of the crank shaft of the engine in revolutions per minute by Formula No. 5, will therefore be

$$N = 33{,}000 \frac{40}{38.9 \times 3 \times 113} = 100 \text{ revolutions per minute.}$$

The following formula may be used in place of Formula No. 1, if so desired:

$$HP = \frac{P \times L \times D^2 \times N}{42{,}000} \qquad (6)$$

Where D is the diameter of the piston in inches, the remainder of the terms used being the same as in Formula No. 1.

TABLE No. 2

Areas of Circles from 3 to 19¾

Diameter	Area of Circle	Diameter	Area of Circle	Diameter	Area of Circle	Diameter	Area of Circle
3	7.07	5½	23.76	10	78.54	15	176.71
3⅛	7.67	5⅝	24.85	10¼	82.52	15¼	182.65
3¼	8.30	5¾	25.97	10½	86.59	15½	188.69
3⅜	8.95	5⅞	27.11	10¾	90.76	15¾	194.83
3½	9.62	6	28.27	11	95.03	16	201.06
3⅝	10.32	6¼	30.68	11¼	99.40	16¼	207.39
3¾	11.04	6½	33.18	11½	103.87	16½	213.82
3⅞	11.79	6¾	35.78	11¾	108.43	16¾	220.35
4	12.57	7	38.48	12	113.10	17	226.98
4⅛	13.36	7¼	41.28	12¼	117.86	17¼	233.71
4¼	14.19	7½	44.18	12½	122.72	17½	240.53
4⅜	15.03	7¾	47.17	12¾	127.68	17¾	247.45
4½	15.90	8	50.26	13	132.73	18	254.47
4⅝	16.80	8¼	53.46	13¼	137.89	18¼	261.59
4¾	17.72	8½	56.74	13½	143.14	18½	268.80
4⅞	18.66	8¾	60.13	13¾	148.49	18¾	276.12
5	19.64	9	63.62	14	153.94	19	283.53
5⅛	20.63	9¼	67.20	14¼	159.48	19¼	291.04
5¼	21.65	9½	70.88	14½	165.13	19½	298.65
5⅜	22.69	9¾	74.66	14¾	170.87	19¾	306.35

EXAMPLE: Calculate the horsepower of the same engine by Formula No. 6.

ANSWER: As the square of the diameter of the piston is $4\times4=16$, then

$$HP = \frac{90.2 \times 1 \times 16 \times 300}{42{,}000} = 10.31 \text{ horsepower.}$$

On the basis of these formulas, two simple rules may be derived for calculating the horsepower of a steam engine:

1. The horsepower is equal to the average effective pressure in pounds per square inch, multiplied by twice the piston stroke in feet, by the area of the piston in square inches and by the number of revolutions of the crank shaft per minute, divided by 33,000.

2. The horsepower is equal to the average effective pressure in pounds per square inch, multiplied by twice the piston stroke in feet, by the square of the diameter of the piston in inches and by the number of revolutions of the crank shaft per minute, divided by 42,000.

It should always be borne in mind that 14.7 pounds must in any case be deducted from the average pressure to obtain the average effective pressure on the piston, whether the average pressure is obtained from an indicator diagram, from Table No. 1, or from Formula No. 2 or 7.

Areas of circles and squares of diameters from 3 to 15¾ are given in Tables No. 2 and 3. These are intended for use in connection with Formulas 1 to 10.

Formulas No. 7, 8, 9 and 10 are, as in the case of Formulas 2, 3, 4 and 5, for the purpose of obtaining the average effective on the piston, the revolutions per minute of the crank shaft of the engine, the diameter of the cylinder or piston, and the piston stroke in feet being given, then

$$P = 42{,}000 \frac{HP}{L \times D^2 \times N} \qquad (7)$$

Where P is the average effective pressure on the piston in pounds per square inch,

$$L = 42{,}000 \frac{HP}{P \times D^2 \times N} \qquad (8)$$

Where L is equal to twice the piston stroke in feet.

$$D^2 = 42{,}000 \frac{HP}{P \times L \times N} \text{ and}$$

$$D = 204.9 \sqrt{\frac{HP}{P \times L \times N}} \qquad (9)$$

Where D is the diameter of the cylinder or piston in inches, and

$$N = 42{,}000 \frac{HP}{P \times L \times D^2} \qquad (10)$$

Where N is the number of revolutions of the crank shaft of the engine per minute.

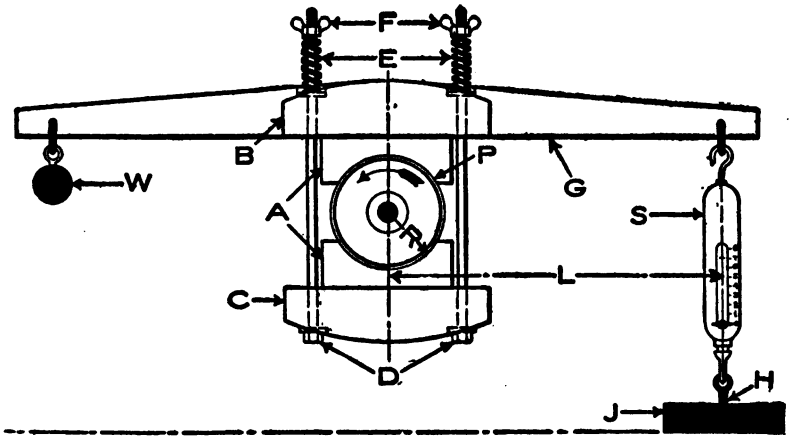
TABLE No. 3

Squares of Diameters from 3 to 19¾

Number	Square of Number	Number	Square of Number	Number	Square of Number	Number	Square of Number
3	9.00	5½	30.25	10	100.00	15	225.00
3⅛	8.77	5⅝	31.64	10¼	105.06	15¼	232.56
3¼	10.56	5¾	33.06	10½	110.25	15½	240.25
3⅜	11.39	5⅞	34.52	10¾	115.56	15¾	248.06
3½	12.25	6	36.00	11	121.00	16	256.00
3⅝	13.14	6¼	39.06	11¼	125.56	16¼	264.06
3¾	14.00	6½	42.25	11½	132.25	16½	272.25
3⅞	15.016	6¾	45.56	11¾	138.06	16¾	280.56
4	16.00	7	49.00	12	144.00	17	289.00
4⅛	17.02	7¼	52.56	12¼	150.06	17¼	297.56
4¼	18.06	7½	56.25	12½	156.25	17½	306.25
4⅜	19.14	7¾	60.06	12¾	162.56	17¾	315.06
4½	20.25	8	64.00	13	169.00	18	324.00
4⅝	21.39	8¼	68.06	13¼	175.56	18¼	333.06
4¾	22.56	8½	72.25	13½	182.25	18½	342.25
4⅞	23.77	8¾	76.56	13¾	189.06	18¾	351.56
5	25.00	9	81.00	14	196.00	19	361.00
5⅛	26.27	9¼	85.56	14¼	203.06	19¼	370.56
5¼	27.56	9½	90.25	14½	210.25	19½	380.25
5⅜	28.89	9¾	95.06	14¾	217.56	19¾	390.06

BRAKE HORSEPOWER

The actual horsepower of an engine, that is, the power or energy in foot-pounds delivered at the driving shaft, can be correctly ascertained only by means of a brake test. This is done by the use of the Prony brake.



A-A—Brake Blocks. B-C—Clamping Pieces. D-D—Clamping Bolts. E-E—Clamping Springs. F-F—Thumb-nuts. G—Brake Lever. H—Eye-bolt. J—Weight. S—Spring Scales. W—Balance Weight.

FIG. 1.—PRONY BRAKE

The apparatus for making a brake test is illustrated in Fig. 1. Two brake blocks partially surround a pulley located on the outer end of the driving shaft of the engine or motor and are attached to two clamping pieces, which hold the brake blocks upon the rim of the pulley by means of bolts, springs and adjusting nuts. The brake lever is made double

ended for the dual purpose of balancing itself and also supplying a place of attachment for the weight which is used to balance the weight of the spring scale used to make the brake test with.

When using the Prony brake, the engine or motor is started in the direction indicated by the arrow, the brake blocks are then tightened by means of the springs and thumb-nuts. The reading of the spring scale and the speed of the pulley are then taken. The engine or motor should be tested at varying speeds and the pull on the spring scale noted for each different speed. The actual horsepower can then be calculated for each test by means of the following formula, and what is known as the critical speed of the engine or motor determined, that is, the speed at which it develops the greatest brake horsepower with the least consumption of fuel.

Let L be the length of the scale lever in inches, and P the pull indicated by the spring scale in pounds. If R be the number of revolutions per minute of the pulley and BHP the actual or brake horsepower of the motor, then

$$\text{BHP} = \frac{\text{L} \times \text{P} \times \text{R}}{63{,}025} \qquad (11)$$

EXAMPLE: An engine of 5 inches bore and stroke, at 300 revolutions of the pulley per minute gives a pull on the spring scale of 32 pounds, the scale lever being 48 inches long. What is the brake horsepower of the engine?

ANSWER: Forty-eight inches multiplied by 32 and 300 equals 460,800—this divided by 63,025 gives 7.30 as the actual or brake horsepower of the motor, or if BHP be the brake horsepower required, then by Formula No. 11,

$$\text{BHP} = \frac{48 \times 32 \times 300}{63{,}025} = 7.30 \text{ horsepower.}$$

INDICATED HORSEPOWER

The thermal or heat efficiency of an engine may be readily determined from an indicator card or diagram, as it gives a representation of the actual conditions within the cylinder during the entire cycle of operation.

The indicator diagram gives the initial pressure in the cylinder before expansion takes place. It also indicates whether the volume of the charge is diminished during its admission to the cylinder. It indicates when the expansion begins and the average pressure of expansion during the stroke. It gives the terminal pressure at the opening of the exhaust. It shows the point of opening of the exhaust. It shows the rapidity of the exhaust. It indicates the back pressure on the piston due to the exhaust. It gives the average pressure during the stroke.

The usual method of obtaining the average pressure from an indicator diagram is by ascertaining its area by means of an instrument known as a planimeter, which is used to calculate the area of irregular surfaces. By moving the tracing point attached to the planimeter over the irregular outline of the diagram, its area is obtained. The area of the diagram divided by its horizontal length, gives the mean vertical height or ordinate of the diagram. The initial pressure in pounds as shown by the diagram multiplied by this mean ordinate, gives the average pressure in pounds per square inch during the entire piston stroke.

For the purpose of ascertaining the average pressure, it is sometimes sufficiently accurate to calculate the mean ordinate by means of vertical measurement lines, or ordinates, drawn upon the diagram, which should divide the diagram

into any desired number of rectangular panels of equal width. The sum of the length of these vertical ordinates, divided by the number of the ordinates will give the mean ordinate required, which, multiplied by the initial pressure, will give the average pressure required. From this the indicated horsepower may readily be found by the use of Formula No. 1 or 6, under "Calculated Horsepower."

EXAMPLE: With 64.7 pounds average pressure calculated from the indicator diagram taken from an engine of 5 inches bore and stroke at 300 revolutions of the crank shaft per minute, what will be the indicated horsepower of the engine?

ANSWER: The average effective pressure on the piston in pounds per square inch will be 64.7 less 14.7, which equals 50 pounds. The area of the piston is 19.64 square inches and the total piston stroke 0.83 feet. As the speed is 300 revolutions of the crank shaft per minute, then by Formula No. 1, if IHP be the indicated horsepower, then

$$\text{IHP} = \frac{50 \times 0.83 \times 19.64 \times 300}{33{,}000} = 7.44 \text{ horsepower.}$$

By Formula No. 6, as the square of the diameter of the cylinder is 25, then,

$$\text{IHP} = \frac{50 \times 0.83 \times 25 \times 300}{42{,}000} = 7.44 \text{ horsepower.}$$

POINT OF CUT-OFF

As steam is ordinarily admitted to the cylinder of an engine by the valve for only a portion of the piston stroke, more pressure and consequently more power can be obtained from a steam engine, by allowing the full boiler pressure to communicate with the cylinder for 80 per cent of the piston stroke. When the steam is admitted to the cylinder for 80 per cent of the piston stroke, the increase of power resulting therefrom is by no means proportional to the increased expenditure of steam, as compared to the case when the steam is admitted to the cylinder for only 30 per cent of the piston stroke.

Less power is obtained from the engine when the steam is admitted to the cylinder for more than 80 per cent of the piston stroke, on account of the back pressure exerted by the steam against the piston on its return stroke. Not only is less power given by the engine, but it is obtained less economically as regards waste of fuel and steam. That point in the piston stroke at which the steam is no longer admitted to the cylinder by the valve is called the point of cut-off.

When the point of cut-off is at one-third of the piston stroke, the steam let into the cylinder during this time goes on expanding during the remaining two-thirds of the piston stroke and by its expansion does useful work. It also loses its high pressure and high temperature, and is discharged into the atmosphere after giving up a great deal of its heat energy.

If the cut-off be earlier than three-tenths of the piston stroke the advantage gained by expansion is counterbalanced

TABLE No. 4

Natural Logarithms of Numbers—1 to 25

No.	Natural Log.	No.	Natural Log.	No.	Natural Log.	No.	Natural Log.
1.01	0.009	2.25	0.811	3.50	1.253	4.75	1.558
1.05	0.049	2.30	0.833	3.55	1.267	4.80	1.569
1.10	0.095	2.35	0.854	3.60	1.281	4.85	1.579
1.15	0.139	2.40	0.876	3.65	1.295	4.90	1.589
1.20	0.182	2.45	0.896	3.70	1.308	4.95	1.599
1.25	0.223	2.50	0.916	3.75	1.321	5.00	1.609
1.30	0.262	2.55	0.936	3.80	1.335	5.05	1.619
1.35	0.300	2.60	0.956	3.85	1.348	5.10	1.629
1.40	0.336	2.65	0.975	3.90	1.361	5.15	1.639
1.45	0.372	2.70	0.993	3.95	1.374	5.20	1.649
1.50	0.405	2.75	1.012	4.00	1.386	5.25	1.658
1.55	0.438	2.80	1.029	4.05	1.399	5.30	1.668
1.60	0.470	2.85	1.047	4.10	1.401	5.35	1.677
1.65	0.501	2.90	1.065	4.15	1.423	5.40	1.686
1.70	0.530	2.95	1.082	4.20	1.435	5.45	1.696
1.75	0.559	3.00	1.098	4.25	1.447	5.50	1.705
1.80	0.588	3.05	1.115	4.30	1.459	5.55	1.714
1.85	0.615	3.10	1.134	4.35	1.470	5.60	1.723
1.90	0.642	3.15	1.147	4.40	1.482	5.65	1.732
1.95	0.668	3.20	1.163	4.45	1.493	5.70	1.741
2.00	0.693	3.25	1.179	4.50	1.504	5.75	1.749
2.05	0.718	3.30	1.194	4.55	1.515	5.80	1.758
2.10	0.741	3.35	1.209	4.60	1.526	5.85	1.766
2.15	0.765	3.40	1.224	4.65	1.537	5.90	1.609
2.20	0.788	3.45	1.238	4.70	1.548	5.95	1.78

TABLE NO. 4—CONT.

Natural Logarithms of Numbers—1 to 25

No.	Natural Log.	No.	Natural Log.	No.	Natural Log.	No.	Natural Log.
6.00	1.792	7.25	1.981	8.50	2.140	9.75	2.277
6.05	1.800	7.30	1.988	8.55	2.145	9.80	2.282
6.10	1.808	7.35	1.995	8.60	2.152	9.85	2.288
6.15	1.816	7.40	2.002	8.65	2.158	9.90	2.293
6.20	1.824	7.45	2.002	8.70	2.163	9.95	2.298
6.25	1.833	7.50	2.015	8.75	2.169	10.00	2.303
6.30	1.840	7.55	2.022	8.80	2.175	10.25	2.327
6.35	1.848	7.60	2.028	8.85	2.180	10.50	2.351
6.40	1.856	7.65	2.035	8.90	2.186	10.75	2.375
6.45	1.864	7.70	2.041	8.95	2.192	11.00	2.397
6.50	1.872	7.75	2.048	9.00	2.197	12.00	2.485
6.55	1.879	7.80	2.054	9.05	2.203	13.00	2.563
6.60	1.887	7.85	2.061	9.10	2.208	14.00	2.639
6.65	1.895	7.90	2.067	9.15	2.214	15.00	2.710
6.70	1.902	7.95	2.073	9.20	2.219	16.00	2.775
6.75	1.909	8.00	2.079	9.25	2.225	17.00	2.833
6.80	1.917	8.05	2.086	9.30	2.231	18.00	2.890
6.85	1.924	8.10	2.091	9.35	2.235	19.00	2.944
6.90	1.932	8.15	2.099	9.40	2.241	20.00	2.996
6.95	1.939	8.20	2.104	9.45	2.246	21.00	3.044
7.00	1.946	8.25	2.110	9.50	2.251	22.00	3.091
7.05	1.953	8.30	2.116	9.55	2.256	23.00	3.036
7.10	1.960	8.35	2.122	9.60	2.262	24.00	3.178
7.15	1.967	8.40	2.128	9.65	2.267	25.00	3.219
7.20	1.974	8.45	2.134	9.70	2.272	30.00	3.378

by the fact that, if steam be admitted to the cylinder for a less portion of the stroke, it will, in expanding, cool the wall of the cylinder so much as to cause the fresh charge of steam during the next piston stroke to condense instead of expanding and doing useful work.

Therefore the point of cut-off, to have certain definite limits of economy, should be between three-tenths and eight-tenths of the piston stroke.

The exact value of the expansion portion of the piston stroke may be readily obtained by referring to a table of natural logarithms, for, when the curve is hyperbolic, the natural logarithm expresses the relation between the area during expansion and the area during admission.

If the steam is cut off at half stroke, it is expanded to twice its original volume, and if the area during admission = 1, then the area during expansion = the natural logarithm of 2, hence

$$\text{the total area} = 1 + \text{nat. log. } 2.$$

Now, on referring to Table No. 4, the natural logarithm of 2 is found to be .693, then

$$\text{the total area} = 1 + .693$$
$$= 1.693$$

and if R = the ratio of expansion, or the volume of the steam at the end of the stroke, divided by the volume at the point of cut-off,

$$\text{then the area during expansion} = \text{nat. log. } R,$$
$$\text{and the total area} = 1 + \text{nat. log. } R.$$

The following table gives the proportional values of the work done for various degrees of expansion.

The work done by the steam during admission is taken as 1, and corresponds with the area inclosed by the rectangle YA, Figs. 6, 7 and 8 (The Adiabatic Curve).

TABLE No. 5

Work Done by Steam During Admission and Expansion

Point of Cut-Off	Ratio of expansion = R	Work done during Admission	Work done during expansion =nat. log. R	Total work done
Cut off at $\frac{3}{4}$ stroke.....	$1\frac{1}{3}$	1	0.262	1.262
Cut off at $\frac{1}{2}$ stroke.....	2	1	0.693	1.693
Cut off at $\frac{1}{3}$ stroke.....	3	1	1.098	2.098
Cut off at $\frac{1}{4}$ stroke.....	4	1	1.386	2.386
Cut off at $\frac{1}{5}$ stroke.....	5	1	1.609	2.609
Cut off at $\frac{1}{8}$ stroke.....	8	1	2.079	3.079
Cut off at $\frac{1}{9}$ stroke.....	9	1	2.197	3.197
Cut off at $\frac{1}{10}$ stroke.....	10	1	2.302	3.302

From this table it may be seen that, if the steam is cut off at one-third of the stroke, and expanded to the end, the work done is about twice that done by the steam during admission.

The exact proportion is 1 : 2.098.

If the steam had been admitted at its initial pressure throughout the whole stroke, three times the weight of steam would have been used, and the proportion of the work done in the two cases, supplying steam through the whole length of the stroke, or cutting off at one-third and expanding, would be as 3 to 2.098, in other words, to get half as much more work out of the engine, three times the weight of steam, and therefore also weight of fuel, will be consumed in the first case as compared with the second.

AVERAGE STEAM PRESSURE

The average steam pressure on the piston in pounds per square inch is usually obtained from an indicator diagram, but it may also be found, if the initial steam pressure in the cylinder and the point of cut-off be known, by reference to Table No. 1.

EXAMPLE: What is the average steam pressure in pounds per square inch, with an initial pressure of 120 pounds per square inch and the steam being cut off at one-third of the piston stroke?

ANSWER: Column 6 in Table No. 1, opposite 120 pounds, gives 83.9 as the average steam pressure in pounds per square inch, corresponding to a cut-off at one-third of the piston stroke. The average steam pressure on the piston in pounds per square inch may be also calculated from the following formula:

$$P = p\left(\frac{\text{Nat. Log. } R + 1}{R}\right) \qquad (12)$$

Where P is the average steam pressure required, p the initial pressure in the cylinder before the steam supply is cut off and R the ratio of expansion of the steam, which is equal to the whole length of the piston stroke divided by the distance the piston travels before the steam is cut off.

EXAMPLE: What is the ratio of expansion with a piston stroke of 10 inches, when the steam supply is cut off after the piston has traveled three inches?

ANSWER: Ten inches divided by 3 inches equals $3\frac{1}{3}$ as the required ratio of expansion.

EXAMPLE: What is the mean pressure on the piston with

the above ratio of expansion of $3\frac{1}{3}$ and an initial pressure of 100 pounds?

ANSWER: From Table No. 4 the nearest number corresponding to $3\frac{1}{3}$ is 3.35, the natural logarithm of which is 1.209, or, in round numbers 1.21. Then, by Formula No. 4 the mean pressure is

$$P = 100\left(\frac{1.21 + 1}{3.33}\right) = 66.34 \text{ pounds.}$$

The average steam pressure during the entire piston stroke should not be confounded with the mean pressure, which is the effective pressure of the steam during the expansion part of the piston stroke only, and is only used in connection with the calculation of the horsepower of compound and triple or quadruple expansion steam engines.

The usual method of ascertaining the average pressure on the piston from an indicator card or diagram, is by means of a planimeter, Fig. 2, which is used to calculate the area of any irregular plane surface, by moving a tracing point attached to the instrument over the irregular boundary line of the figure.

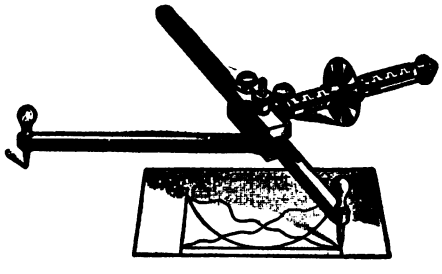


FIG. 2.—PLANIMETER

In many cases it is found to be sufficiently accurate to calculate the average pressure by means of ordinates or vertical measurement lines, drawn upon the indicator diagram.

EXPANSION OF STEAM

If advantage be taken of the expansive properties of steam then with steam at 100 pounds absolute pressure, expanded down to 15 pounds without back pressure, a very considerable increase is made in the work done.

For the steam is expanded 6.66 times, and the useful work is therefore 1 + natural log. 6.66 = 1 + 1.896 = 2.896.

That is, if the work done by 1 pound of steam at 15 pounds pressure equals 1, then by using the same weight of steam at 100 pounds pressure and expanding it down to 15 pounds without back pressure, nearly three times the amount of work is done per pound of steam used, and also per pound of fuel consumed, for the consumption of fuel depends upon the weight of steam used, and is nearly independent of the pressure of the steam, owing to the fact that the total heat in steam at high pressures is only a very little greater than the total heat in steam of lower pressures.

BACK PRESSURE

Back pressure has a considerable influence on the total work done by a given weight of steam.

If the piston of a steam engine to be acted upon on one side by steam of 45 pounds absolute pressure, and if it be possible let there be no pressure acting on the other side of the piston. Then, if the pressure of the steam were maintained uniform throughout the stroke, the diagram of pressure and volume would be a simple rectangle.

But in non-condensing engines, when the steam acts on

one side of the piston, communication is open with the atmosphere by means of the exhaust port on the other side, and it is, therefore, exposed to a back pressure of 14.7 pounds per square inch. The effective pressure is therefore 45 — 14.7 = 30.3 pounds per square inch, and the effect on the diagram is to remove all the lower part from zero to 14.7 pounds, and thus reduce the area of the figure, and therefore also the effective work done. In practice there is always an additional back pressure of 3 to 5 pounds, due to the incompleteness of the exhaust, making a total back pressure of about 18 to 20 pounds per square inch. It may be much more than this with higher piston speeds. If the cylinder were placed during the exhaust into communication with a condenser, then a large portion of the atmospheric pressure would be removed, and a back pressure of not more than about 3 pounds absolute would oppose the motion of the piston. In this case the area of the figure representing the effective work done would be extended to within about 3 pounds of the vacuum line, the gain of work being proportional to the gain of area, while the weight of steam used in each case is clearly the same.

The effective pressure on the piston therefore equals the difference between the pressures on each side of the piston.

AVERAGE EFFECTIVE PRESSURE

To find the average effective pressure of steam per square inch on the piston, by measurement from the indicator diagram, when a planimeter is not at hand:

Divide the line of volumes into eight or ten equal parts.

Measure the height of the diagram at each division by the scale of pressures.

Add these measurements together, and divide the sum by the number of measurements. The result will give the mean average effective pressure per square inch on the piston.

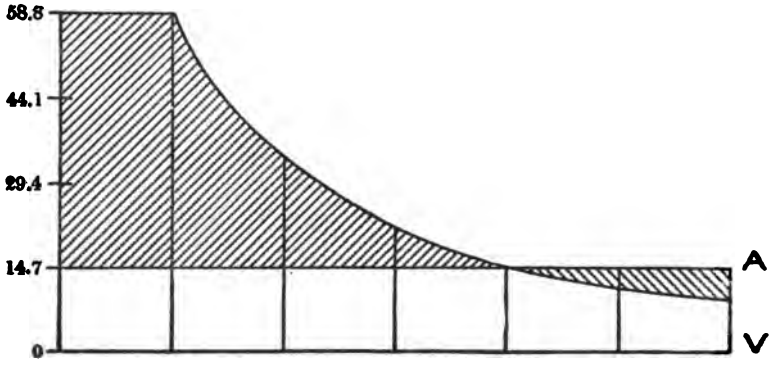


FIG. 3.—EXPANSION CURVE

To find the total average pressure on the piston, multiply the average pressure per square inch by the area of the piston in square inches.

The practical limit of the expansion of steam varies for different types and conditions of engines, and is the point, beyond which no further reduction in weight of steam consumed, per unit of power, can be obtained economically. The

gain by further expansion beyond this point is more than neutralized by the loss from condensation in the cylinder, and from negative work done by the back pressure upon the piston.

It would therefore be useless to expand the steam to a pressure below that of the pressure at the other side of the piston.

Let steam at 44.1 pounds per square inch, or 58.8 pounds per square inch absolute pressure be admitted to the cylinder, and cut off at one-fourth of the stroke of the piston.

The theoretical useful work done by the expanding steam, is shown in Fig. 3, by the shaded portion of the diagram, from the commencement of the piston stroke to the intersection of the expansion curve by the atmospheric pressure line A. The negative or lost work which would be done if the degree of expansion were carried further, is shown by the shaded portion to the right in the diagram and below the atmospheric pressure line A. The pressure of the steam and the back pressure will therefore be equal, and any further extension of the expansion would be useless. In practice the expansion should not be carried as far as this. If the expansion be continued beyond four, to five or six expansions, the work done by the atmosphere against the piston towards the end of the stroke is greater than that done on it by the steam. The steam should never be cut off so early as to cause it to expand to a pressure below that of the back or atmospheric pressure acting against the piston.

As the theoretical limit of the number of the expansions $= \frac{\text{initial pressure}}{\text{back pressure}}$. In the above example the $\frac{\text{initial pressure}}{\text{back pressure}} = \frac{58.8}{14.7} = 4$ expansions. In good practice the maximum number of expansions should not exceed three-fourths of the theoretical limit.

CONDENSATION OF STEAM

If steam be admitted to the cylinder of an engine which is cooler than the entering steam, the steam gives up some of its heat to the cylinder walls, a portion of the steam is condensed and deposited on their surface, and more steam consequently enters the cylinder to take its place, while the temperature of the cylinder walls rises to that of the steam in contact with them.

If the steam were supplied the cylinder at its initial pressure and temperature throughout the whole piston stroke, and the exhaust port be then opened, the steam would escape into the air, and the pressure in the cylinder fall to that of the atmosphere, or nearly so.

But the water which has been formed, being in contact with the walls of the cylinder at the temperature of the initial steam, will evaporate immediately the pressure is reduced by the opening of the exhaust port and become reconverted into steam at the expense of the heat in the walls of the cylinder, thereby cooling them to the temperature of the steam during the exhaust stroke.

The steam thus re-evaporated during the exhaust stroke not only absorbs heat from the cylinder walls, which will have to be made up from the entering steam during the next stroke, but passes away to the air without doing any useful work.

When the piston reaches the end of its stroke, fresh steam is admitted into the cylinder and comes in contact with the cooled surface of the cylinder cover, piston, and steam ports, which have been exposed to the lower temperature of the exhaust steam, and the same process of condensation and re-evaporation is repeated.

Condensation, consequently takes place during the early part of the piston stroke, while re-evaporation occurs partly towards the end of the stroke and partly during the exhaust stroke. The re-evaporation during the expansion behind the piston helps the piston, and increases the total work done, but the steam re-evaporated during the exhaust stroke in a single-cylinder engine is wasted. The loss due to the condensation of steam in the cylinders of all steam engines varies from 10 to 30 per cent, or more, of the steam consumed, the loss becoming greater as the mean temperature of the cylinder walls becomes less than the temperature of the initial steam.

Condensation increases as the degree of expansion in the cylinder increases, because there is a decreasing temperature of the walls with a constant initial temperature of the steam.

The advantage of using high-pressure steam is due to the property it possesses of doing work by expanding behind the piston after the supply of steam is cut off from the cylinder.

There is a limit to the useful expansion of steam in a single cylinder, owing to the excessive condensation in the cylinder with a high degree of expansion, resulting in increased consumption of fuel instead of a saving.

The secret of economy is to supply the cylinder with dry steam, and to maintain it as dry as possible throughout the stroke.

The laws which govern the condensation of steam in the cylinder are not at present fully understood. The means adopted to reduce the amount of water of condensation in the cylinder are:

Having the steam come from the boiler as dry as possible, and maintaining it in the dry condition by carefully covering the pipes traversed by the steam, on its way to the engine with non-conducting material.

Placing a water-separator in the steam-pipe just before entering the engine.

Jacketing the cylinder with hot steam. The addition of the steam jacket reduces the amount of condensation in the cylinder. The jacket is the more necessary the greater the degree of expansion in one cylinder, and the slower the piston speed.

Compression of a portion of the exhaust steam by closing the exhaust port before the end of the piston stroke, and allowing the piston to compress the steam and thereby to raise its pressure and temperature, and also the temperature of the cylinder cover, steam port and piston, before the new steam is admitted.

Increasing the piston speed of the engine.

Superheating the steam, that is, applying additional heat to the steam on its way from the boiler to the engine.

CYLINDER CLEARANCE

The piston in a cylinder when at the end of its stroke should not touch the end or cover of the cylinder, but there should be a certain amount of space left between the piston and cover to prevent their coming into actual contact. In addition to this space, there is the port between the face of the slide valve and the cylinder, by which the steam is conducted to the cylinder. These two spaces, shown at c in Fig. 4, which make up the whole space between the face of the valve and the face of the piston when the piston is at the end of its stroke, are called the clearance.

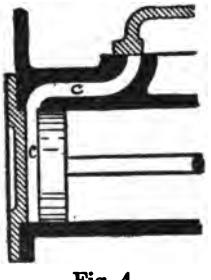


Fig. 4.
CYLINDER CLEARANCE

Let the volume displaced by the piston during its stroke equal 9 cubic feet, and the volume of the clearance equal 1 cubic foot. When steam is admitted to the cylinder 1 cubic foot is used to fill the clearance space before the piston moves and if steam were used at full pressure throughout the piston stroke, 9 cubic feet more would be required to displace the piston. Thus 10 cubic feet of steam passes through the engine without doing any work, representing a loss of 10 per cent.

But suppose the steam is cut off at one-ninth of the stroke. During admission there is required 1 cubic foot of steam to fill the clearance, and which at first does not work on the piston, then another cubic foot to displace the piston when the steam is cut off. There are now 2 cubic feet of steam at initial pressure enclosed in the cylinder. Expansion commences, and at the end of the stroke the volume occupied by the steam will evidently be 10 cubic feet. The pressure of

the steam at the end of the stroke is therefore one-fifth of the initial pressure.

If there had been no clearance then there would have been 1 cubic foot of steam in the cylinder at point of cut-off, which would expand to 9 cubic feet with a terminal pressure of one-ninth of the initial pressure.

Suppose the initial pressure had been 180 pounds absolute pressure. Then, neglecting the effect of clearance, the terminal pressure would be $\frac{180}{9} = 20$ pounds per square inch absolute pressure.

Including the clearance, the terminal pressure would be $\frac{180}{5} = 36$ pounds per square inch absolute pressure, or nearly twice the terminal pressure obtained when the clearance is neglected.

LAP AND LEAD OF SLIDE VALVES

When a valve has no lap, it will move on each side of its central position, in order to open the steam port fully, a distance equal to the width of the port, and would deliver steam to the cylinder the entire length of the piston stroke were not some means employed to prevent this happening. But, when lap is added to the valve, the distance moved on each side of its central position must be increased, if the port is to be fully opened, to the width of the port plus the lap.

This disadvantage is overcome in two ways: By adding **lap** to the valve, that is, by extending the width of its face, and by giving it **lead**, that is, by causing it to move forward so as to open the port just before the piston reaches the end of its stroke. The amount by which the valve overlaps the edges of the steam port when at the middle of its stroke is called the **lap** of the valve.

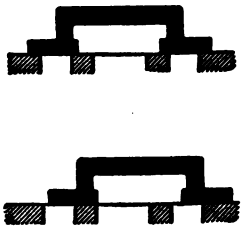


FIG. 5.

LAP AND LEAD OF SLIDE VALVES

The amount by which it overlaps the outside edges is called the **outside lap**.

The amount by which it overlaps the inside edges is called the **inside lap**.

The upper view in Fig. 5 shows a slide valve with both inside and outside lap.

The amount of opening of the port for the admission of steam when the piston is at the beginning of its stroke is called the **lead** of the valve. The opening shown in the lower view in Fig. 5 is the lead of the valve, and the piston at this moment is at the beginning of its stroke.

The inside lap being less than the outside lap, the lead to

the exhaust port is greater than that to the steam port, which permits of a ready escape of the exhaust steam.

The effect of the addition of **Outside lap** is:

To cut off the steam at some earlier point of the stroke.

To require the eccentric to be moved forward on the shaft, which results also in an earlier opening of the exhaust port.

The effect of the addition of **Inside lap** is:

To close the exhaust port at an earlier point in the stroke, producing compression of the steam at the back of the piston.

To delay the opening of the exhaust port

THE ADIABATIC CURVE

Geometrical, arithmetical and graphical methods of laying out the adiabatic or expansion curve of a diagram are illustrated in Figures 6, 7 and 8 and also fully explained in the text accompanying the figures.

In the geometrical method, the condition of the gas as to volume and pressure for the respective piston positions are represented by a series of rectangles of equal area, both of varying dimensions, which are drawn from common volume and pressure lines.

In the arithmetical method the conditions of the gas as to pressure is represented by vertical ordinates corresponding to given piston positions at various points in the stroke.

In the graphical method, the relations between the varying pressures and volumes are given by points obtained from the intersection of vertical ordinates, by diagonal lines drawn from the zero point of pressure and volume to the apex of the vertical ordinates.

GEOMETRICAL DIAGRAM

The relation between the volume and pressure of a gas at a constant temperature is expressed in the following terms, which is known as Boyle's Law:

The volume of a given portion of a gas varies inversely as the pressure, the temperature remaining constant.

This may be illustrated as follows: Let a portion of gas be introduced into a cylinder which is closed at one end and fitted with a slidable piston. The gas will fill every part of the space beneath the piston, and also exert a uniform pres-

sure on each square inch of surface with which it is in contact. If the internal volume of the cylinder be increased by partially withdrawing the piston, the gas will still completely fill the space, but it will be less dense—that is, it will exert a less pressure per square inch of surface with which it is in contact.

If the gas be compressed into a smaller space, it will become more dense, that is to say, it will exert a greater pressure per square inch of surface with which it is in contact.

Boyle's law and the properties of the hyperbolic curve, is diagrammatically illustr ted in Fig. 6 as follows:

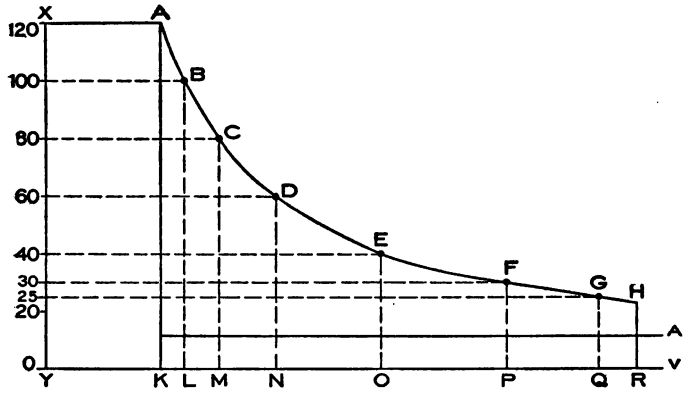


FIG. 6.—GEOMETRICAL DIAGRAM

Draw the horizontal line YR and the vertical line YX at the left-hand end of YR. On the line YX scale off the pressures as given on the diagram and draw horizontal lines from the intermediate points of pressure. Draw the rectangle OA, which represents the volume of steam at the point of cut-off, which, in this case, is taken as one-fifth of the piston stroke, or a ratio of 5. To complete the curve the distance of the points L, M, N, O, P and Q from the point Y must be ascertained and perpendicular lines erected at these points

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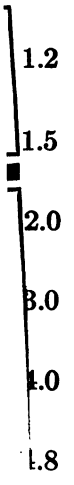

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ARITHMETICAL DIAGRAM

To plot the diagram shown in Fig. 7, draw the horizontal line YS, which should equal the length of the piston stroke in inches, then draw the vertical line YX, and divide it into 6 equal parts as shown, or into any other suitable number desired. As the steam in this case is cut off at one-fifth of the stroke, the horizontal line YS should be divided into 10 equal parts to properly approximate the shape of the curve. Then YK is the volume of the steam and p the pressure at the point A where the steam is cut off. As the initial pressure on the piston at A is 120 pounds per square inch, then

$$\text{Pressure at B} = \frac{YK}{YL} \times p = \tfrac{2}{3} \times 120 = 80.0$$

$$\text{Pressure at C} = \frac{YK}{YM} \times p = \tfrac{2}{4} \times 120 = 60.0$$

$$\text{Pressure at D} = \frac{YK}{YN} \times p = \tfrac{2}{5} \times 120 = 50.0$$

$$\text{Pressure at E} = \frac{YK}{YO} \times p = \tfrac{2}{6} \times 120 = 40.0$$

$$\text{Pressure at F} = \frac{YK}{YP} \times p = \tfrac{2}{7} \times 120 = 34.3$$

$$\text{Pressure at G} = \frac{YK}{YQ} \times p = \tfrac{2}{8} \times 120 = 30.0$$

$$\text{Pressure at H} = \frac{YK}{YR} \times p = \tfrac{2}{9} \times 120 = 26.7$$

$$\text{Pressure at J} = \frac{YK}{YS} \times p = \tfrac{2}{10} \times 120 = 24.0$$

The foregoing method of ascertaining the pressure at any point during the expansion stroke when the initial pressure and point of cut-off are given, may be expressed as follows:

Multiply the initial pressure in pounds per square inch by the distance the piston has traveled at the point of cut-off, and divide by the distance of the given point from the beginning of the piston stroke.

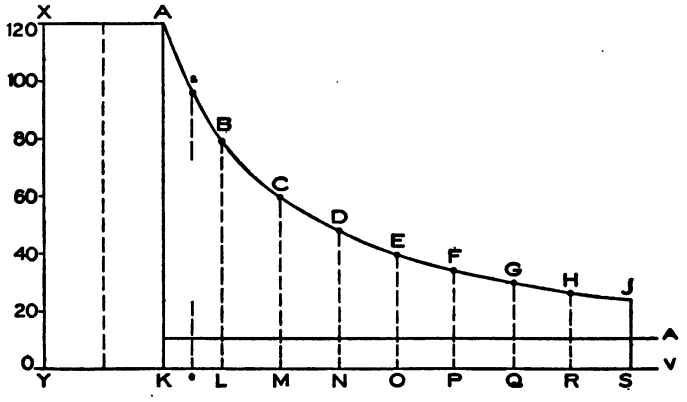

FIG. 7.—ARITHMETICAL DIAGRAM

To obtain still greater accuracy in plotting the curve, ordinates or perpendiculars may be calculated for intermediate points, as shown by the line **ae**. When plotting theoretical diagrams, the pressures must always be measured from the vacuum or absolute pressure line V of the diagram. The atmosphere or gauge pressures are measured from the atmospheric pressure line A, or they may be found by subtracting 14.7 pounds from the absolute pressure at the given point.

GRAPHICAL DIAGRAM

The hyperbolic curve may be drawn without any calculation whatever by the simple graphical method shown in Fig. 8.

Draw the lines YS and YX as in Fig. 7, also the lines XJ and JS to complete the rectangle YJ. Draw the line KA to form the rectangle YA. To ascertain the pressure at any point B, corresponding to the volume enclosed by the rectangle OB, draw the vertical line BL and the diagonal line BO, which intersects AK at 1. Then draw a horizontal line from 1 until it intersects BL, this will be the first point in the curve.

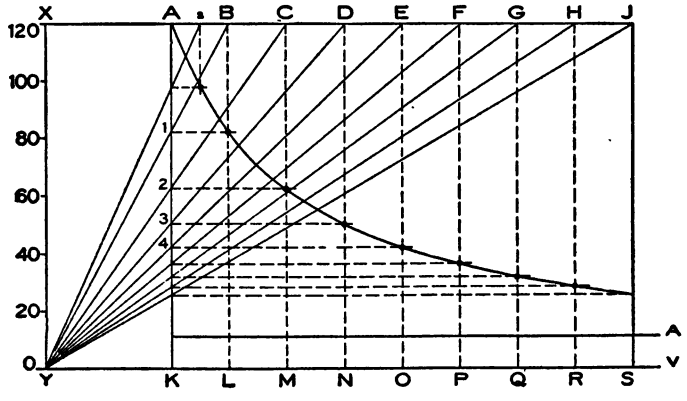

FIG. 8.—GRAPHICAL DIAGRAM

The other points C, D, E, F, G, H and J, may be obtained in a similar manner, and the complete curve drawn through the points. If desired, greater accuracy may be had in plotting the curve as before stated by the use of intermediate points, or ordinates, as shown at **a**.

Boyle's law is not closely followed or obeyed by any known gas, and less so by steam, but the knowledge of this law is of great value in obtaining results which are sufficiently accurate to correspond with the behavior of expanding steam.

HORSEPOWER OF EXPLOSIVE MOTORS

As the formulas used for the calculation of the horsepower of steam engines are not as a rule directly applicable to explosive motors, formulas are here given that will be found better suited to the purpose.

From a theoretical standpoint a two-cycle explosive motor should not only have as great a speed as a four-cycle motor, but should be capable of developing almost twice the power It is a fact, however, that in actual practice the performance of a two-cycle motor is far different.

The horsepower of a two or four-cycle explosive motor may be calculated from the following formulas:

$$HP = \frac{D^2 \times S \times N}{21{,}000} \text{ (Two-cycle).} \qquad (13)$$

Where D is the diameter and S the stroke of the piston in inches, N the number of revolutions of the crank shaft per minute and HP the required horsepower.

EXAMPLE: Required the horsepower of a two-cycle motor of 6 inches bore and stroke at 600 revolutions of the crank shaft per minute?

ANSWER: The square of the bore multiplied by the stroke is equal to 216, which multiplied by 600 and divided by 21,000, gives 6.17 as the required horsepower, or by Formula No. 13

$$HP = \frac{36 \times 6 \times 600}{21{,}000} = 6.17 \text{ horsepower.}$$

For a four-cycle explosive motor, the formula is given herewith:

$$HP = \frac{D^2 \times S \times N}{18{,}000} \text{ (Four-cycle).} \qquad (14)$$

EXAMPLE: What horsepower should be developed by a four-cycle motor of 6 inches bore and stroke at 600 revolutions of the crank shaft per minute?

ANSWER: As the bore and stroke of the motor are alike, the square of the bore multiplied by the stroke is equal to the cube of 6, which is 216, this multiplied by 600, and divided by 18,000, gives 7.20 as the horsepower of the motor, or by Formula No. 14,

$$HP = \frac{216 \times 600}{18{,}000} = 7.20 \text{ horsepower.}$$

If the mean pressure upon the piston be known, the horsepower of a two or four-cycle explosive motor may be readily calculated from Formulas No. 1 or 6.

To ascertain the mean pressure on the piston of an explosive motor by means of an indicator diagram, at speeds over 500 revolutions of the crank shaft per minute, is almost an impossibility on account of the limitation in the speed of the partial rotation of the indicator drum. For motor speeds above this limitation, the mean pressure must be calculated from a theoretical diagram.

An ideal diagram for an explosive motor is shown in Fig. 9. Before plotting the diagram it is necessary to know the degree of compression, or the ratio between the volume of the combustion chamber or compression space and the cubic contents of the volume swept out by the piston, which is generally known as the piston displacement.

In calculating the pressures at various points in the curves the following formulas are used. For the compression curve

$$CP = 14.7 \times N^{1.3}. \qquad (15)$$

Where CP is the pressure required at any point in the compression curve and N the degree of compression in atmospheres.

The constant 14.7 represents the pressure of the atmosphere in pounds per square inch at sea level.

The formula for the expansion curve is

$$EP = \frac{p}{E^{1.4}} \qquad (16)$$

Where EP is the expansion pressure after ignition at any point in the curve and p the maximum pressure of the combustion, and R the ratio of expansion in volumes.

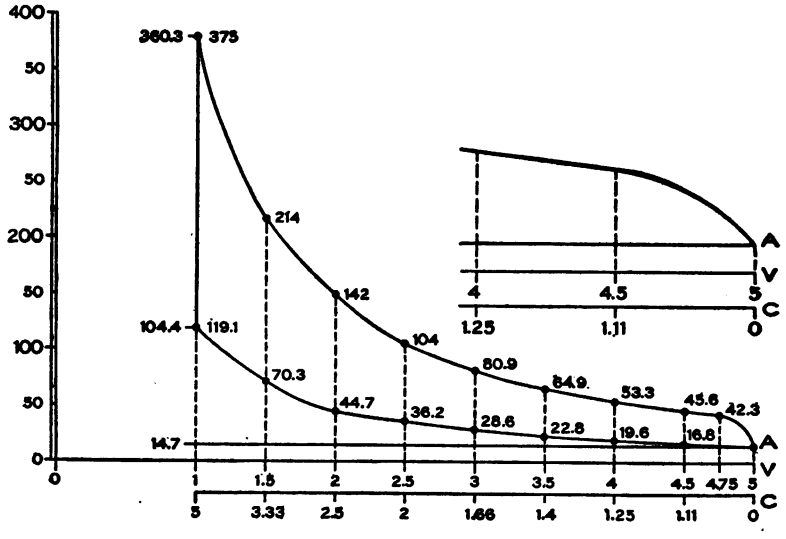

FIG. 9.—GAS ENGINE DIAGRAM

In order to show how to apply the foregoing formulas, the plotting of the diagram shown in Fig. 9 will be undertaken. The degree of compression used in the diagram is 5 atmospheres and the proportion of air to gasoline vapor is taken as 9 to 1.

The line V shown in the diagram is the vacuum or absolute pressure line and the line A the atmospheric pressure line. All

vertical measurements on the diagram are plotted from the absolute pressure line. The various degrees of compression in atmospheres are given on the line C and the ratios of expansion on the line V. As the compression pressure is equal to the atmospheric pressure multiplied by the degree of compression raised to the 1.3 power, resource must be had to a table of common logarithms to ascertain the values of N to the 1.3 power at the various points in the compression stroke.

To show the method of ascertaining the various degrees of pressure during the compression stroke, the pressure at the end of the compression stroke will be calculated as an example. Then by Formula No. 15,

$$CP = 14.7 \times 5^{1.3} = 14.7 \times 8.10 = 119.1 \text{ pounds.}$$

From Table No. 7, the logarithm of 5 is found to be 0.6990. This, multiplied by 1.3, gives 0.9087. From the table the number corresponding nearest to this logarithm is 8.10, which, multiplied by 14.7, gives 119.07 or, in round numbers, 119.1 as the pressure in pounds per square inch above a vacuum at the end of the compression stroke. The pressure above the atmosphere will therefore be 119.1 — 14.7, which equals 104.4 pounds per square inch. The pressures at all the other points in the compression curve may be readily calculated in a similar manner. From the rule accompanying Table No. 6, page 75, the initial explosive force corresponding to 5 atmospheres compression and a mixture of air and gasoline vapor of 9 to 1, is equal to the explosive force at atmospheric pressure multiplied by the degree of compression, which is therefore 75×5, which equals 375 pounds per square inch absolute pressure, or 360.3 pounds at atmospheric or gauge pressure.

The pressures for the expansion curve may now be ascertained by means of Formula No. 16, as follows:

Find the pressure when the charge has expanded to two volumes. As P equals 375 and R equals 2, then

$$EP = \frac{375}{2^{1.4}} = \frac{375}{2.64} = 142.0 \text{ pounds.}$$

From Table No. 7, the logarithm of 2 is 0.3010, which, multiplied by 1.4, gives 0.4214. From the table the nearest corresponding number is 2.64. This, divided by 375 gives 142.0 as the required pressure in pounds per square inch at expansion to 2 volumes. The remaining pressures for the expansion curve may be found in a similar manner.

The abrupt curve at the end of the expansion stroke is produced by the exhaust taking place before the piston has quite reached the end of its outward or expansion stroke. The curve shown in the upper view in Fig. 9 shows the proper point of release or opening of the exhaust for high speed explosive motors such as automobile and marine types.

The method of plotting the diagram having been fully explained, the mean pressure during the piston stroke may now be calculated from the ordinates shown in the diagram. As the diagram is divided into 8 equal parts, then (375 — 119.1) + (214—70.3.) + (142 — 44.7) + (104 — 36.2)+(80.9 — 28.6) + (64.9 — 22.8) + (53.3 — 19.6) + (45.6 — 16.8) equals 721.6, which divided by 8 gives 90.2 as the mean absolute pressure on the piston, the mean effective pressure will therefore be 90.2 — 14.7, which equals 75.5 pounds per square inch.

Knowing the mean effective pressure, the indicated horsepower may then be readily found by means of Formula No. 1 or 6, Calculated Horsepower.

When plotting a diagram such as is shown in Fig. 9, the distance on the line V, from O to 1, represents the clearance or compression space in terms of the piston displacement and the distance 1 to 5, the piston displacement which is usually represented by the length of the piston stroke in inches. The

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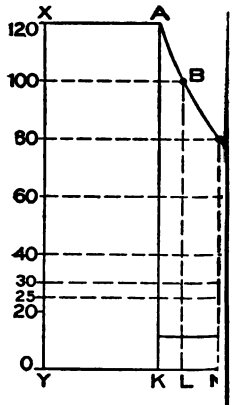

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to intersect the points B, C, D, E, F and G, then assuming YK to equal one,

$$YL = \frac{YX}{BL} = \frac{120}{100} = 1.2$$

$$YM = \frac{YX}{CM} = \frac{120}{80} = 1.5$$

$$YN = \frac{YX}{DN} = \frac{120}{80} = 2.0$$

$$YO = \frac{YX}{EO} = \frac{120}{40} = 3.0$$

$$YP = \frac{YX}{FP} = \frac{120}{30} = 4.0$$

$$YQ = \frac{YX}{GQ} = \frac{120}{25} = 4.8$$

The rectangles OA, OB, OC, OD, OE, OF, OG represent the conditions as to volume and pressure for the piston positions, AK, BL, CM, DN, EO, FP and GQ, as these rectangles are all equal in area, for $120\times1=100\times1.2=80\times1.5=60\times2.00=40\times3.0=30\times4.0=25\times4.8$.

The curve thus plotted represents the changes in volume and pressure for a gas when the temperature is kept uniform throughout the piston stroke. The curve describes fairly accurately the relation between the varying pressures and volumes of steam expanding in the cylinder of an engine.

This curve may be plotted without regard to the length of the piston stroke, as it is dependent only on the initial pressure and the number of times the gas is expanding above its original volume.

To ascertain the point of piston travel for any given expansion pressure:

Divide the initial pressure of the steam before expansion, by the expansion pressure at the desired point. The result

EXAMPLE: Find the cubic contents of the combustion space for a motor of 4½-inch bore and 6-inch stroke, with 5 atmospheres compression.

ANSWER: The area corresponding to 4½ inches diameter is 15.90 square inches, then 6 multiplied by 15.90 equals 94.40, which divided by 5 minus 1, or 4, gives 23.6 as the number of cubic inches required, or by Formula No. 18,

$$C = \frac{6 \times 15.90}{(4-1)} = 23.6 \text{ cubic inches.}$$

THE INDICATOR

The uses to which the indicator is generally applied may be stated as follows:

To obtain a diagram showing the condition or the behavior of the gases in the cylinder of an engine, the promptness of the admission, the fall in pressure from heat losses, the extent and character of the expansion, the efficiency of the exhaust, the extent of the back pressure upon the piston and the amount of compression at the end of the stroke.

To find the average effective pressure exerted by the steam upon the piston, from which to calculate the indicated horsepower of the engine.

To determine whether the valves have sufficient area and also whether they are set correctly, by taking diagrams from the cylinder and noting the points of admission, cut-off, exhaust and compression.

An indicator consists primarily of a small steam cylinder, containing a piston, and a spring to regulate the movement of the piston according to the pressure. A pencil or recording device, carried by an arrangement of small rods and levers, constituting a parallel motion, by means of which the pencil reproduces the vertical movement of the indicator piston but exaggerated four or five times. A drum, to which a paper, called a card, is attached, and which receives a partial forward and backward rotation on its axis by means of a reducing gear operated from the crosshead or other suitable part of the engine.

By the combined vertical movement of the pencil and the horizontal movement of the paper or card, a closed figure is drawn which is called an indicator diagram. The diagram as

traced on the card by the pencil of the indicator, differs more or less from the theoretical diagrams illustrated in Figs. 6, 7 and 8—The Adiabatic Curve. An actual indicator diagram, however, is considered the more perfect the closer it approaches the outlines of the theoretical diagram.

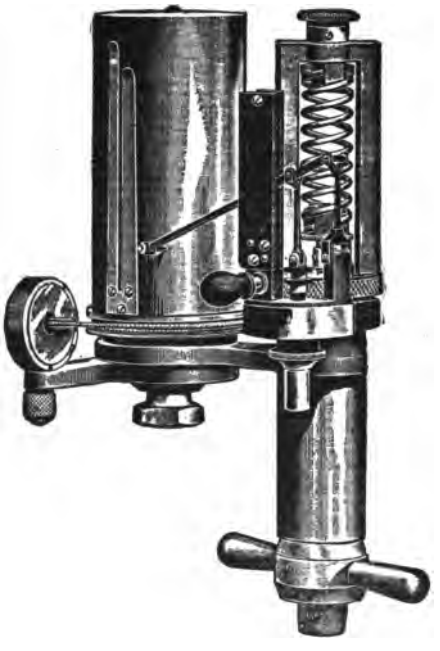


FIG. 10.—TABOR INDICATOR

Fig. 10 shows an outside view of one form of the Tabor indicator, with outside connected piston spring.

Fig. 11 illustrates the construction of the same make of indicator, but with inside connected spring. It consists of a steam cylinder A, containing a piston B, and spring C. The spring is secured to the piston at one of its ends and to the cover of the cylinder at the other end, and the pressure

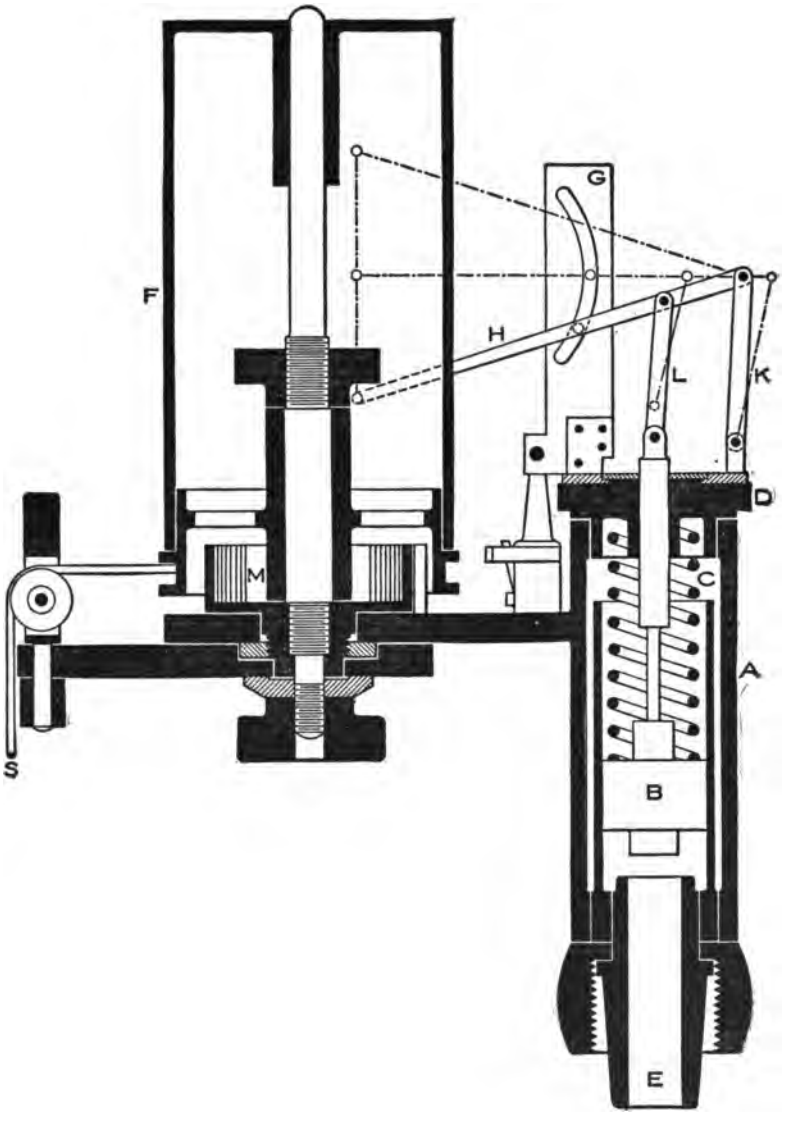


FIG. 11.—SECTIONAL VIEW OF TABOR INDICATOR

of the steam or gas which enters the indicator cylinder through the opening E, compresses the spring to a certain amount, depending on the pressure. The movement of the piston is transferred to the paper on the drum F, and multiplied five times by means of the levers shown in the drawing. The noticeable feature of this form of indicator is the means employed to secure a straight-line movement of the pencil. A plate, G, containing a curved slot, is fixed in an upright position, and a small roller, attached to the pencil lever, is so fitted as to roll freely in the slot. The curve of the slot is of such shape that it exactly counteracts the tendency of the pencil to describe a circular arc in the opposite direction to that of the slot, and the mark made by the pencil on the drum is consequently a straight line, when the drum is not in motion. The pencil mechanism consists of three pieces, the pencil-bar, H, the back link, K, and the piston-rod link, L.

The two links K and L are always parallel to each other, no matter what their position may be. The lower pivots of the links L and K, and the pencil point always form a straight line. The paper drum is attached by a cord, S, to a suitable reducing motion from the engine, the cord pulls the drum around on its axis with a movement corresponding to that of the piston of the engine, the return movement of the drum being accomplished by the coil spring M within the indicator drum.

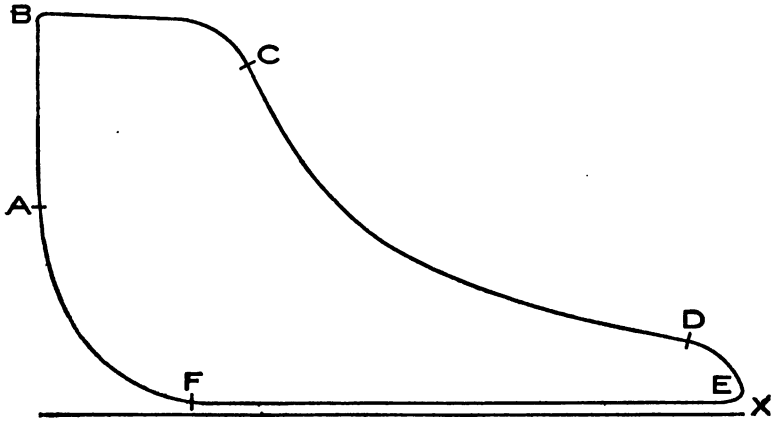
INDICATOR DIAGRAMS

An example of an indicator diagram taken from a single expansion steam engine and operating under good working conditions is shown in Fig. 12.

The line AB shows the rise of pressure of the steam as it enters the cylinder of the engine. This is called the **admission line.**

The line BC shows how nearly the steam pressure in the

cylinder reaches the boiler pressure. This is called the **steam line**. The difference between the steam pressure in the cylinder and the boiler pressure may be ascertained by measuring the height of the point B above the atmospheric pressure line A with a scale corresponding to the scale of the indicator spring, and afterwards drawing a horizontal line above the point, which should be laid out with the same scale to represent the boiler pressure. There is always a certain amount



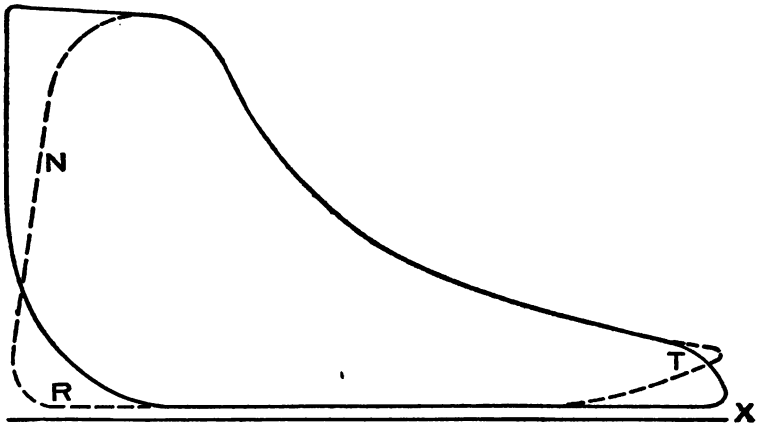
A. Point of Admission. AB. Admission Line. BC. Steam Line. CD. Expansion Curve. DE. Exhaust Curve. EF. Back-pressure Line. F. Point of Closing of Exhaust. FA. Compression Curve. X. Atmospheric Pressure Line.

FIG. 12

of drop in pressure between the cylinder of the engine and the boiler, due to the throttling of the steam supply in the ports and passages of the cylinder, especially at high speeds, or with too long or too small diameter steam pipes, or with steam pipes having too short bends or turns.

The point of cut-off C is more or less sharp and well defined with trip-gear or Corliss type of valve-gear which

cut off suddenly by the action of a strong spring or a dash-pot. With the slide valve the cut-off is much more gradual, the corner is rounder, and the exact point of cut-off is sometimes difficult to locate. In such cases the point of cut-off may be taken as the tangent between the convex curve of the cut-off and the concave curve of the expansion line.



N. Insufficient Lead. T. Late Exhaust. R. Late Compression. X. Atmospheric Pressure Line.

FIG. 13

The **exhaust point** D occurs just before the end of the piston stroke. With high speed engines it is very important to have an early exhaust, as the greatest trouble is usually not to get the steam into the cylinder, but to get it out.

The **exhaust curve** DE represents the drop in pressure which occurs at the opening of the exhaust port.

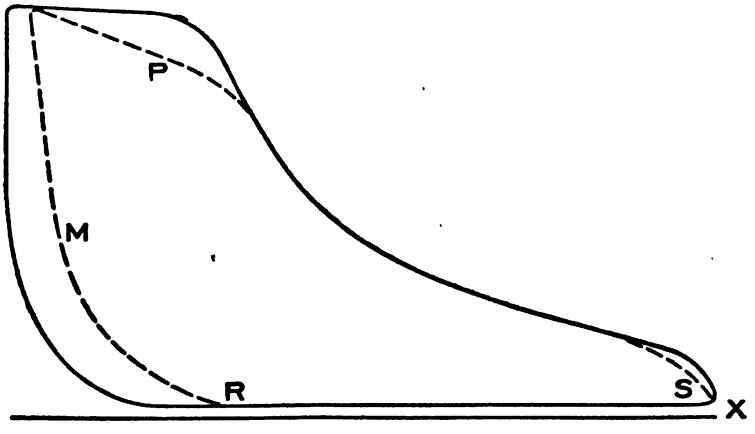
The **back-pressure line** EF shows the amount of back or negative pressure on the piston during its return stroke.

The **compression curve** FA starts at the commencement of the closing of the exhaust port at the point F. This point depends upon the amount of inside lap on the valve

and the angular advance of the eccentric. The shape of this curve will depend entirely upon the amount of steam left in the cylinder after the closing of the exhaust port and the volume of the clearance space.

Figures 13 and 14 show how an indicator diagram may be distorted by various causes, as shown by the dotted lines in the diagrams and fully explained below the figures.

The **expansion curves** of indicator diagrams vary considerably and they do not obey any well-defined law. They are, as a rule, the result of a variety of separate causes which operate in a different manner in different engines, sometimes in the same engine by a change of conditions.



P. Wiredrawing of Steam. M. Excessive Lead. S. Early Exhaust. R. Early Compression. X. Atmospheric Pressure Line.

FIG. 14

ELECTRICAL HORSEPOWER

Force is any cause of change of motion of matter. It is usually expressed by volts, pounds or other units.

Resistance is a counter-force or whatever opposes the action of another force.

Work is force exercised in traversing or crossing a space against a resistance or counter-force. Force multiplied by space or distance represents work in foot-pounds.

Energy is the capacity for doing work, and is measured by the work done.

The cause of a manifestation of energy is force. If this be electro-motive energy or electric energy in current form it is called **electro-motive force**. The practical unit of electro-motive force is the **Volt**.

When electro-motive force does work in a closed electric circuit a current is produced. The practical unit of current is called the **Ampere**.

A current of electricity, when flowing in a closed electric circuit, passes through some substances more easily than through others.

The relative ease of passage of the electric current is known as conductance. In practical calculations its reciprocal, which is called resistance, is generally used. This practical unit is known as the **Ohm**.

A current of one **Ampere** is maintained by one **Volt** through a resistance of one **Ohm**.

Ohm's law may be generally stated under the following heads:

The current is in direct proportion to the voltage of the circuit, and inversely proportional to its resistance.

1. The current is equal to the voltage divided by the resistance of the circuit.

2. The voltage is equal to the current multiplied by the resistance of the circuit.

3. The resistance of the circuit should equal the voltage divided by the current required.

One electrical horsepower is equal to the current in amperes multiplied by the electro-motive force or voltage of the circuit and divided by 746.

Let C be the current in amperes and E the voltage of the circuit. If EHP be the required electrical horsepower, then

$$\text{EHP} = \frac{\text{E} \times \text{C}}{746} \qquad (19)$$

EXAMPLE: What is the electrical horsepower of a 200-volt motor, which takes a current of 80 amperes?

ANSWER: As the voltage is 200 and the current 80 amperes then by Formula No. 19,

$$\text{EHP} = \frac{200 \times 80}{746} = 21.44 \text{ horsepower.}$$

Table No. 8 gives the electrical horsepower of motors with voltage from 20 to 200 volts, and current strengths from 10 to 80 amperes.

The mechanical efficiency of an electric motor may be found by use of the table as follows:

EXAMPLE: Required the mechanical efficiency of a 40-volt, 60-ampere motor, which is rated by its maker as of 3.25 horsepower—the motor when under full load using 80 amperes.

ANSWER: Reference to the column in the table corresponding to 40 volts and 60 amperes gives 3.22, while the 80-ampere column gives 4.29. Then 3.22 divided by 4.29 gives 0.75, or 75 per cent, as the mechanical efficiency of the motor.

An electro-motive force of one **volt**, with a current strength of one **ampere**, is capable of developing an amount of work or energy called a **watt.**

One electrical horsepower is equal to **746 watts.**

One volt multiplied by **one ampere** is therefore equal to **one watt**, that is

$$W = E \times C \tag{20}$$

The square of **current** multiplied by the **resistance** is also equal to the number of **watts**, then

$$W = C^2 \times R \tag{21}$$

The square of the **electro-motive force or voltage**, divided by the **resistance** is also equal to the **watts**, that is

$$W = \frac{E^2}{R} \tag{22}$$

If C be the current in amperes, E the electro-motive force or voltage and R the resistance, then

$$EHP = \frac{C^2 \times R}{746} = \frac{E^2}{746 \times R} \tag{23}$$

In practice with motors of small power, 1,000 watts are necessary to deliver one mechanical or brake horsepower at the driving shaft of the motor.

If the actual or brake horsepower of an electric motor be known, the efficiency of the motor may be readily found by the following formula:

If E be the voltage of the circuit and C the current in amperes consumed by the motor, let BHP be the brake horsepower of the motor and e the efficiency of the motor, then

$$e = \frac{BHP \times 746}{E \times C} \tag{24}$$

EXAMPLE: What is the mechanical efficiency of a 200-

volt motor, which when taking a current of 80 amperes, shows on a brake test, 17.16 horsepower?

ANSWER: As the brake horsepower is 17.16 the voltage 200 volts and the current 80 amperes, then by Formula No. 24,

$$e = \frac{17.16 \times 746}{200 \times 80} = 80 \text{ per cent.}$$

SPECIFIC HEAT

The ratio of the amount of heat required to raise the temperature of a substance one degree to the amount of heat required to raise an equal weight of water one degree is called the specific heat of the substance.

The specific heat of bodies varies very considerably, as will be seen from the following table:

Water = 1.000	Wrought Iron = 0.113	Lead = 0.031
Cast Iron = 0.130	Copper = 0.100	Mercury = 0.033
Steel = 0.118	Bismuth = 0.031	Coal = 0.241

Water has the highest specific heat of any substance except hydrogen, and the metals have the lowest. In other words it takes more heat to raise the temperature of a given weight of water than any other substance.

ABSOLUTE TEMPERATURE

The zero of temperature on the Centigrade and Fahrenheit scales has been chosen arbitrarily, on one the Zero being the freezing point of water, and on the other a point 32 degrees Fahrenheit below it.

For scientific purposes it is necessary to have a uniform zero, and such a point, called the zero of absolute temperature, has been chosen, the position of which is 461 degrees Fahrenheit, below the zero Fahrenheit, or 273 degrees Centigrade, below the zero Centigrade.

Hence to express degrees Fahrenheit in degrees of absolute temperature, add 461. Thus the boiling point of water at atmospheric pressure = 212 degrees Fahrenheit = 212+461 = 673 degrees absolute temperature.

To convert degrees Fahrenheit into degrees Centigrade: Subtract 32, multiply the remainder by 5, and divide by 9.

Thus, convert 158 degrees Fahrenheit to degrees Centigrade.

Then $(158 - 32)\ \frac{5}{9} = 70$ degrees Centigrade.

Or, to convert degrees Centigrade into degrees Fahrenheit: Multiply by 9, divide by 5, and add 32.

Thus, convert 70 degrees Centigrade into degrees Fahrenheit.

Then $(70 \times \frac{9}{5}) + 32 = 158$ degrees Fahrenheit.

HEAT

If one pound of cold water be heated in a closed vessel till the water becomes warm, although the temperature of the water has changed, its weight remains the same; and if the heat be continued until all the water is converted into steam, provided none of the steam can escape, the total weight of the steam is still exactly the same as that of the water from which it is produced.

It is evident, therefore, that the heat which produced these changes is without weight. Heat cannot, therefore, be a material substance. It was formerly thought to be some kind of subtle fluid, which flowed from hot bodies into colder ones. This theory is no longer accepted, because it was found that heat could be developed to an unlimited extent from cold bodies merely by rubbing them together.

A piece of cold iron can be made red hot by hammering it. A carpenter's saw or machinist's chisel or turning tool soon get hot when a rubbing action or friction, is set up between the tool and the work, although they are all quite cold to begin with.

All bodies are assumed to be composed of minute particles called molecules, held together by mutual attraction or cohesion and these molecules are in a state of continual agitation or vibration. The hotter the body the more vigorous the vibration of its constituent particles. In solid bodies the vibrations are limited in extent. If this limit is exceeded, owing to addition of heat, cohesion is sufficiently overcome to enable the particles to move about freely and without restriction, and the solid has now become a liquid. On still continuing the heat, further separation of the molecules takes place, cohesion is completely overcome, and they fly off in all directions. The liquid then becomes a gas.

The unit of heat is the amount of heat necessary to raise the temperature of one pound of water one degree Fahrenheit when the water is at its greatest density, namely, from 39 to 40 degrees Fahrenheit. Table No. 9 gives the heat of combustion of various materials or combustibles. Their relative efficiency as fuels may be readily ascertained from the table.

The rate of transfer of heat from a hot body to a cold is proportional to the difference of temperature between the two bodies. The greater the difference of temperature the greater the rate of flow of heat.

The transfer of heat from one to the other may take place in any of the following ways· namely, by radiation, convection, or conduction.

Heat is given off from hot bodies in rays which radiate in all directions in straight lines. The heat from the burning coal in a furnace is transferred to the crown and sides of the furnace by radiation, it passes through the furnace plates by conduction and the water is heated by convection.

The process by which heat passes from hotter to colder parts of the same body, or from a hot body to a colder body in contact with it, is called conduction. A bar of iron having one end placed in the fire soon becomes hot at the other

extremity, the heat being conducted from particle to particle throughout its entire length.

A piece of burning wood can be held with the hand close to the burning part. Some bodies, therefore, conduct heat much more readily than others.

The following table gives the relative conducting power of metals:

Silver, 100	Brass, 23	Steel, 11.6
Copper, 74	Iron, 11.9	Lead, 8.5

Let water at 32 degrees Fahrenheit be heated in a closed vessel, such as an ordinary steam boiler, containing space for the accumulation of steam, and let heat be gradually applied. Then the temperature of the water will gradually rise to that corresponding to the pressure within the boiler, after which evaporation commences and steam is formed.

As the heat is increased, the temperature, pressure, and density, or weight per cubic foot, of the steam increases indefinitely, so long as the strength of the boiler is not exceeded and the relation between the temperature, pressure, and density always bears a certain fixed relation, as given by Table No. 10.

If just sufficient heat is supplied as to maintain the temperature constant, the pressure and density remain constant also, and evaporation ceases. If a communication be opened between the boiler and engine, on escape of steam from the boiler the pressure is momentarily reduced and re-evaporation commences rapidly. So long as the temperature is maintained, no sensible variation of pressure is noticeable in a boiler supplying steam to an engine.

MENSURATION OF SURFACE AND VOLUME

To find the circumference of a circle, multiply the diameter by 3.1416.

To find the diameter of a circle, multiply the circumference by .31381.

To find the area of a circle multiply the square of the diameter by .7854.

To find the area of a triangle, multiply the base by one-half the perpendicular height.

Area of the sector of a circle equals the area of the circle multiplied by the number of degrees in the arc, divided by 360.

Area of the surface of a cylinder equals the circumference multiplied by the length, plus the area of both ends.

To find the diameter of a circle with a given area: Divide the area by .7854, and extract the square root.

To find the volume of a cylinder: Multiply the area of the section in square inches by the length in inches, this equals the volume in cubic inches. Cubic inches divided by 1728 equals the volume in cubic feet of any body.

The surface of a sphere is equal to the square of the diameter multiplied by 3.1416.

Volume of a sphere is equal to the cube of the diameter multiplied by .5236.

The side of an inscribed cube equals the radius of the sphere multiplied by 1.1547.

The area of the base of a pyramid or cone, whether round, square or triangular, multiplied by one third of its height equals the volume.

A gallon of water (United States Standard) weighs 8⅓ pounds and contains 231 cubic inches. A cubic foot of water weighs 62½ pounds, and contains 1.728 cubic inches, or 7½ gallons.

Each nominal horsepower of a boiler requires one cubic foot of water per hour.

To find the internal area of a pipe, the volume and velocity of the fluid or gas being given, multiply the number of cubic feet by 144, and divide the product by the velocity in feet per minute. The area being found, it is easy to find the diameter of pipe necessary.

To find the pressure in pounds per square inch of a column of water of given height, multiply the height of the column in feet by .434. Approximately, every foot elevation is equal to one-half pound pressure per square inch.

To find the velocity in feet per minute necessary to discharge a given volume of fluid or gas in a given time, multiply the number of cubic feet by 144, and divide the product by the internal area of the pipe in inches.

Doubling the diameter of a pipe increases its capacity four times.

Steam rising from water at its boiling point, 212 degrees, has a pressure equal to the atmosphere or 14.7 pounds to the square inch.

A standard horsepower: The evaporation of 30 pounds of water per hour from a feed water temperature of 100 degrees Fahrenheit into steam at 70 pounds gauge pressure.

To find the capacity of a tank of any size, given the dimensions of a cylinder in inches, to find its capacity in U. S. gallons: Square the diameter, multiply by the length and by .0034.

To ascertain the heating surface in tubular boilers, multiply two-thirds of the circumference of the boiler by the length of boiler in inches and add to it the area of all the tubes.

On the surface of the earth we live, as it were, at the bottom of an aerial sea, which is called the atmosphere, and its weight causes a pressure in every direction of 14.7 pounds per square inch.

Gauge pressures are usually reckoned from the pressure of the atmosphere. Thus a pressure gauge, when its index finger points to 10 pounds, indicates a pressure of 10 pounds above the atmospheric pressure. To express this in absolute pressure add the pressure of the atmosphere to the gauge pressure.

Thus 10 pounds pressure on a gauge equals 10 plus 14.7, equals 24.7 pounds pressure absolute.

NATURAL LOGARITHMS

Natural logarithms of numbers are based on the number

$$e = 2.718282,$$

which is the fixed value to which the expression

$$\left(1+\frac{1}{m}\right)^m$$

approaches as m becomes indefinitely great, and which is also the sum of the infinite series.

$$1+\frac{1}{1\times 1}+\frac{1}{1\times 2}+\frac{1}{1\times 2\times 3}+\frac{1}{1\times 2\times 3\times 4}+\text{etc.}$$

Common logarithms of number are derived from natural logarithms by multiplying the natural logarithm by the number

$$0.434294$$

which is called the modulus of the common system of logarithms, that is,

$$\text{Common log.} = \text{natural log.} \times 0.434294 = \frac{\text{natural log.}}{2.302585}.$$

Natural logarithms may be found from common logarithms by dividing the common logarithm by the modulus, that is,

$$\text{Natural log.} = \frac{\text{Common log.}}{0.434294} = \text{Common log.} \times 2.302585.$$

Table No. 4, page 22, gives the natural logarithms of numbers from 1 to 25.

COMMON LOGARITHMS

Logarithms are the exponents of a series of powers and roots of numbers. The logarithm of a number is that exponent of some other number, which renders the power of the other number, which is denoted by the exponent, equal to the former. In other words, the logarithm of a number is the exponent of the power to which the number must be raised to give a given base.

When the logarithms of numbers form a series in arithmetical progression, their corresponding natural numbers form a series in geometrical progression, thus:

Common logarithms	0	1	2	3	4
Natural numbers	1	10	100	1,000	10,000

Natural logarithms were the invention of Lord Napier. Common logarithms, the kind in general use, were invented by Prof. Briggs of Oxford. Logarithms are extremely useful in abridging the labor of mathematical calculations.

The addition and subtraction of common logarithms correspond to the multiplication and division of their natural numbers.

In a like manner, involution is performed by multiplying the common logarithm of any number by the number denoting the required power, and evolution by dividing the common logarithm of the number denoting the required root.

The common logarithm of a number consists of two parts,

an integral part or whole number, which is called the characteristic, and a decimal called the mantissa.

To find the common logarithm of a given number from Table No. 7, page 76, proceed as follows:

The first two figures of the number will be found in the vertical column to the extreme left in the table, and the third figure of the number in the horizontal row at either the top or bottom of the table. Having found the first two figures of the number, always neglecting the decimal, pass along the line opposite these figures until the column headed by the third figure of the number is reached. The number thus found will be the mantissa or decimal fraction of the logarithm. The characteristic will depend upon the number of figures, less one, in the number, counting from the left of the decimal point. If the decimal point be entirely to the left of the number, the characteristic is obtained by counting the number of cyphers before the number, to the right and adjacent to the decimal point.

EXAMPLE: Find the common logarithm of 5.06 from Table No. 7.

ANSWER: In the row of figures opposite 50 and in the column under 6, the mantissa of the logarithm is .7042. Counting from the decimal place of the number to the left, the characteristic will be one less than the number of figures to the right of the decimal, which is, in this case 1, and 1 minus 1 equals zero, which is the characteristic of the mantissa .7042, the complete logarithm of 5.06 will then be 0.7042.

The logarithm of 0.506 is -1.7042
The logarithm of 5.06 is 0.7042
The logarithm of 50.6 is 1.7042
The logarithm of 506 is 2.7042

To find the number corresponding to a given logarithm: As the mantissa of the given logarithm is not usually found

in the table, select the four figures corresponding nearest to the given mantissa. The first two figures of the number will be found in the column marked "No." at the left of the row in which is the mantissa selected, and the third or last figure of the number at the top or bottom of the vertical row of figures.

EXAMPLE: Find the number from Table No. 7 corresponding to logarithm 1.0334.

ANSWER: The first two figures of the number corresponding to the mantissa .0334 are 10, and at the top of the vertical column the third figure is given as 8, making the three figures 108. As the characteristic is 1 therefore the actual number is 10.8.

The number corresponding to -1.0334 is .108
The number corresponding to 0.0334 is 1.08
The number corresponding to 1.0334 is 10.8
The number corresponding to 2.0334 is 108

To multiply one or more numbers together, add the common logarithms of the numbers together, the sum will be the logarithm of the required number.

To divide a number by one or more numbers, subtract the sum of the common logarithms of the numbers from the logarithms of the number to be divided.

The mantissa of the common logarithm of 6 is the same as the mantissa of 60 or 600, the characteristic only being changed thus:

Common logarithm of .600 = -1.7782
Common logarithm of 6.00 = 0.7782
Common logarithm of 60.0 = 1.7782
Common logarithm of 600 = 2.7782

Table No. 7 gives the common logarithms of numbers from 100 to 999.

The logarithm of a number may also be readily found from

Table No. 7 as follows: Mantissa of the logarithm of 70.4 is .8476, then counting from the decimal point of the number to the left, thus 0—1, the characteristic of the logarithm is 1, and the complete logarithm of 70.6 is 1.8476.

A decimal point must always be prefixed to the mantissa of a logarithm obtained from the table, before affixing the characteristic.

TABLE No. 6

Thermo-dynamic Properties of Gasoline and Air

Degree of Compression in Atmospheres.	Gauge Pressure in Pounds per Square Inch.	Temperature after Compression in Degrees Fahrenheit.	Isothermal or Heat Pressure in Pounds per Square Inch.	Initial Explosive Pressure in Pounds per Square Inch after Ignition. Mixture of Gasoline Vapor and Air.			
				1 to 11	1 to 9	1 to 7	1 to 5
1.00	0	60	0	*60	*75	*85	*90
1.68	10	145	28.9	101	126	143	151
2.02	15	178	36.7	121	152	172	182
2.36	20	207	45.9	142	177	201	212
2.70	25	234	53.5	162	202	230	243
3.04	30	252	62.4	182	228	259	274
3.38	35	281	71.6	202	254	287	304
3.72	40	302	81.1	223	279	316	335
4.06	45	321	90.9	244	304	345	365
4.40	50	339	100.9	264	330	375	396
4.74	55	357	111.2	284	356	403	427
5 08	60	375	121.6	305	381	432	457
5.42	65	389	132.3	325	406	461	468
5.76	70	405	143.2	346	432	489	518
6.10	75	420	154.3	366	458	518	549
	1	2	3	4	5	6	7

*Explosive force in pounds per square inch at atmospheric pressure.

The Adiabatic or Gauge Pressure is given in Table No. 6 as well as the theoretical Isothermal or Heat-pressure resulting from the compression. This latter pressure is more or less problematical in actual practice as it depends largely on the design and speed of the motor.

The values of the Initial Explosive Pressure given in the table are obtained by multiplying the Degree of Compression in atmospheres by the explosive force at atmospheric pressure, of the varying mixtures given.

The Isothermal or Heat-pressure and the Initial Explosive Pressure after ignition are given in absolute pressures, that is the pressure within the cylinder. To obtain Adiabatic or Gauge Pressures, 14.7 pounds must be deducted from the figures given in columns 3, 4, 5, 6 and 7.

TABLE No. 7

Logarithms of Numbers from 100 to 999

No.	0	1	2	3	4	5	6	7	8	9	Diff.
10	0000	0043	0086	0128	0170	0212	0253	0294	0334	0374	40
11	0414	0453	0492	0531	0569	0607	0645	0682	0719	0755	37
12	0792	0828	0864	0899	0934	0969	1004	1038	0172	1106	33
13	1139	1173	1206	1239	1271	1303	1335	1367	1399	1430	31
14	1461	1492	1523	1553	1548	1614	1644	1673	1703	1732	29
15	1761	1790	1818	1847	1875	1903	1931	1959	1987	2014	27
16	2041	2068	2095	2122	2148	2175	2201	2227	2253	2279	25
17	2304	2330	2355	2380	2405	2430	2455	2480	2504	2529	24
18	2553	2577	2601	2625	2648	2672	2695	2718	2742	2765	23
19	2788	2810	2833	2856	2878	2900	2923	2459	2967	2989	21
20	3010	3032	3054	3075	3096	3118	3139	3160	3181	3201	21
21	3222	3243	3263	3284	3304	3324	3345	3365	3385	3404	20
22	3424	3444	3464	3483	3502	3522	3541	3560	3579	3598	19
23	3617	3636	3655	3674	3692	3711	3729	3747	3766	3784	18
24	3802	3820	3838	3856	3874	3892	3909	3927	3945	3962	17
25	3979	3997	4014	4031	4048	4065	4082	4099	4116	4133	17
26	4150	4166	4183	4200	4216	4232	4249	4265	4281	4298	16
27	4314	4330	4346	4362	4378	4393	4409	4425	4440	4456	16
28	4472	4487	4502	4518	4533	4548	4564	4579	4594	4609	15
29	4624	4639	4654	4669	4683	4698	4713	4728	4742	4757	14
30	4771	4786	4800	4814	4829	4843	4857	4871	4886	4900	14
31	4914	4928	4942	4955	4969	4983	4997	5011	5024	5038	13
32	5051	5065	5079	5092	5105	5119	5132	5145	5159	5172	13
33	5185	5198	5211	5224	5237	5250	5263	5276	5289	5302	13
No.	0	1	2	3	4	5	6	7	8	9	Diff.

TABLE No. 7—CONT.

Logarithms of Numbers from 100 to 999

No.	0	1	2	3	4	5	6	7	8	9	Diff.
34	5315	5328	5340	5353	5366	5378	5391	5403	5416	5428	13
35	5441	5453	5465	5478	5490	5502	5514	5527	5539	5551	12
36	5563	5575	5587	5599	5611	5623	5635	5647	5658	5670	12
37	5682	5694	5705	5717	5729	5740	5752	5763	5775	5786	12
38	5798	5809	5821	5832	5843	5855	5866	5877	5888	5899	12
39	5911	5922	5933	5944	5955	5966	5977	5988	5999	6010	12
40	6021	6031	6042	6053	6064	6075	6085	6096	6107	6117	11
41	6128	6138	6149	6160	6170	6180	6191	6201	6212	6222	10
42	6232	6234	6253	6263	6274	6284	6294	6304	6314	6325	10
43	6335	6345	6355	6365	6375	6385	6395	6405	6415	6425	10
44	6435	6444	6454	6464	6474	6484	6493	6503	6513	6522	10
45	6532	6542	6551	6561	6571	6580	6590	6599	6609	6618	10
46	6628	6637	6646	6656	6665	6675	6684	6693	6702	6712	9
47	6721	6730	6739	6749	6758	6767	6776	6785	6794	6803	9
48	6812	6821	6830	6839	6848	6857	6866	6875	6884	6893	9
49	6902	6911	6920	6928	6937	6946	6955	6964	6972	6981	9
50	6990	6998	6007	7016	7024	7033	7042	7050	7059	7067	9
51	7076	7084	7093	7101	7110	7118	7126	7135	7143	7152	8
52	7160	7186	7177	7185	7193	7202	7210	7218	7226	7235	8
53	7243	7251	7259	7267	7275	7284	7292	7300	7308	7316	8
54	7324	7332	7340	7348	7356	7364	7372	7380	7388	7396	8
55	7404	7412	7419	7427	7435	7443	7451	7459	7466	7474	8
56	7482	7490	7497	7505	7512	7520	7528	7536	7543	7551	8
No.	0	1	2	3	4	5	6	7	8	9	Diff.

TABLE NO. 7—CONT.

Logarithms of Numbers from 100 to 999

No.	0	1	2	3	4	5	6	7	8	9	Diff.
57	7559	7566	7574	7582	7589	7597	7604	7612	7619	7627	7
58	7634	7642	7649	7657	7664	7672	7679	7686	7694	7701	8
59	7709	7716	7723	7731	7738	7745	7752	7760	7767	7774	8
60	7782	7789	7796	7803	7710	7818	7825	7832	7839	7846	7
61	7853	7860	7868	7875	7882	7889	7896	7903	7910	7917	7
62	7924	7931	7938	7945	7952	7959	7966	7973	7980	7987	6
63	7993	8000	8007	8014	8021	8028	8035	8041	8048	8055	7
64	8062	8069	8075	8082	8089	8096	8102	8109	8116	8122	7
65	8129	8136	8142	8149	8156	8162	8169	8176	8182	8189	6
66	8195	8202	8209	8215	8222	8228	8235	8241	8248	8254	7
67	8261	8267	8274	8280	8287	8293	8299	8306	8312	8319	6
68	8325	8331	8338	8334	8351	8357	8363	8370	8376	8382	6
69	8388	8395	8401	8407	8414	8420	8426	8432	8439	8445	6
70	8451	8457	8463	8470	8476	8482	8488	8494	8500	8506	7
71	8513	8519	8525	8531	8537	8543	8549	8555	8561	8567	6
72	8573	8579	8585	8591	8597	8503	8609	8615	8621	8627	6
73	8633	8639	8645	8651	8657	8663	8669	8675	8681	8686	6
74	8692	8698	8704	8710	8716	8722	8727	8733	8739	8745	6
75	8751	8756	8762	8768	8774	8779	8785	8791	8797	8802	6
76	8808	8814	8820	8825	8831	8837	8842	8848	8854	8859	6
77	8865	8871	8876	8882	8887	8893	8899	8904	8910	8915	6
78	8921	8927	8932	8938	8943	8949	8954	8960	8965	8971	5
79	8976	8982	8987	8993	8998	9004	9009	9015	9020	9025	6
No.	0	1	2	3	4	5	6	7	8	9	Diff.

TABLE No. 7—CONT.

Logarithms of Numbers from 100 to 999

No.	0	1	2	3	4	5	6	7	8	9	Diff.
80	9031	9036	9042	9047	9053	9058	9063	9069	9074	9079	6
81	9085	9090	9096	9101	9106	9112	9117	9122	9128	9133	5
82	9138	9143	9149	9154	9159	9165	9170	9175	9180	9186	5
83	9191	9196	9201	9206	9212	9217	9222	9227	9232	9238	5
84	9443	9248	9253	9258	9263	9269	9274	9279	9284	9489	5
85	9294	9299	9304	9309	9315	9320	9325	9330	9335	9340	5
86	9345	9350	9345	9460	9465	9469	9474	9479	9484	9489	5
87	9395	9400	9405	9410	9415	9420	9425	9430	9435	9440	5
88	9445	9450	9455	9460	9465	9469	9474	9479	9484	9489	5
89	9494	9499	9504	9509	9513	9518	9523	9528	9533	9538	4
90	9542	9547	9552	9557	9562	9566	9571	9576	9581	9586	4
91	9590	9595	9600	9605	9609	9614	9619	9624	9628	9633	5
92	9638	9643	9647	9652	9657	9661	9666	9671	9675	9680	5
93	9685	9689	9694	9699	9603	9701	9713	9717	9722	9724	4
94	9731	9736	9741	9745	9750	9754	9759	9763	9768	9773	4
95	9777	9782	9786	9790	9795	9800	9805	9809	9814	9818	5
96	9823	9827	9832	9836	9841	9845	9850	9854	9859	9863	5
97	9868	9872	9877	9881	9886	9890	9894	9899	9903	9908	4
98	9912	9917	9921	9926	9930	9934	9939	9943	9948	9952	4
99	9956	9961	9965	9969	9964	9978	9983	9987	9991	9996	4
No.	0	1	2	3	4	5	6	7	8	9	Diff.

TABLE No. 8

Horsepower of Electric Motors

Voltage.	Current in Amperes.										
	10	20	30	40	50	60	70	80	100	120	140
20	.29	.54	.79	1.07	1.34	1.61	1.88	2.14	2.68	3.22	3.76
40	.54	1.07	1.61	2.14	2.68	3.22	3.75	4.29	5.36	6.44	7.50
60	.79	1.61	2.41	3.22	4.02	4.82	5.56	6.43	8.04	9.64	11.12
80	1.07	2.14	3.22	4.29	5.36	6.43	7.50	8.58	10.72	12.86	15.00
100	1.34	2.68	4.02	5.36	6.70	7.94	9.38	10.72	13.40	15.88	18.76
200	2.68	5.36	8.04	10.72	13.40	15.88	18.76	21.44	26.80	31.76	37.52

TABLE No. 9

Heat of Combustion

Combustible.	Total units of heat of combustion per pound.	Pounds of water evaporated from and at 212°.
Hydrogen	62,000	64.2
Carbon burned to carbonic oxide	4,400	4.55
Carbon burned to carbonic acid	14,600	15.0
Anthracite	14,700	15.2
Newport coal	14,000	14.5
Durham coke	13,640	14.1
Wigan cannel coal	14,000	14.5
Petroleum	20,360	21.0
Coal Gas	20,800	21.5
Oak Wood (dry)	7,700	8

When the air for combustion in a boiler furnace passes between the fire-bars under the fuel, combination takes place between the oxygen and the under layers of glowing carbon, forming carbonic acid. This gas, in passing on through the upper layers of carbon, here loses part of its oxygen, and the carbonic acid gas is now reduced to carbonic oxide, the remainder of its oxygen having united with more carbon to form carbonic oxide.

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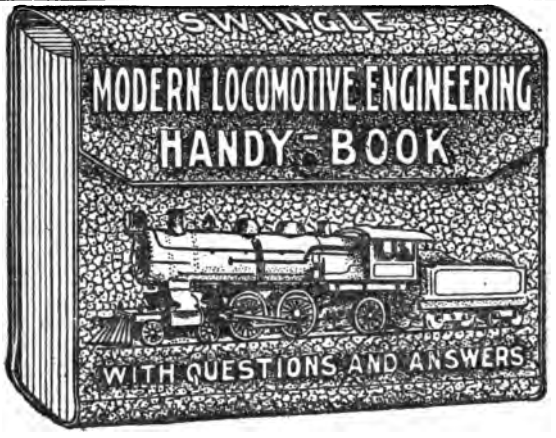

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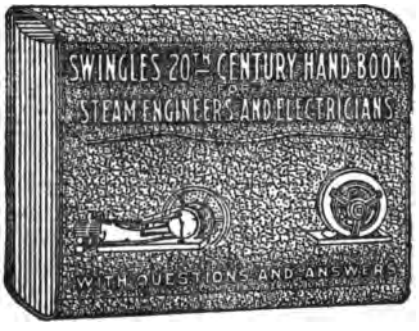

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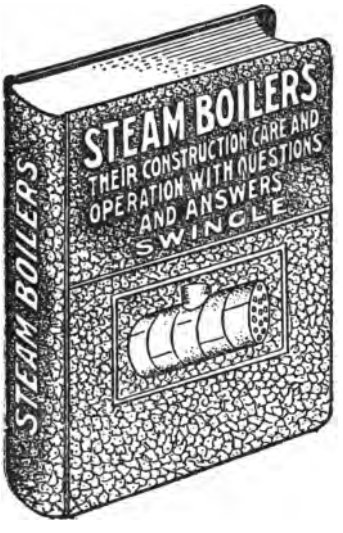

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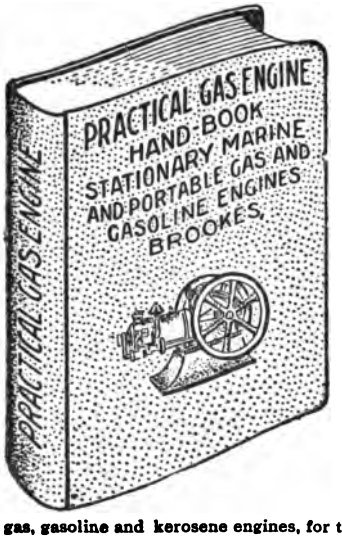

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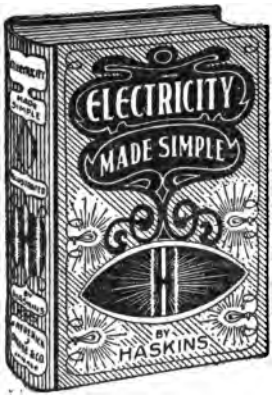

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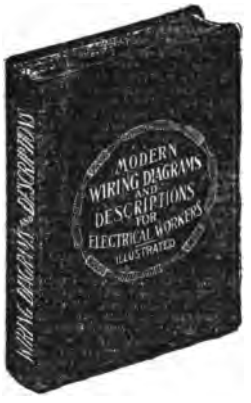

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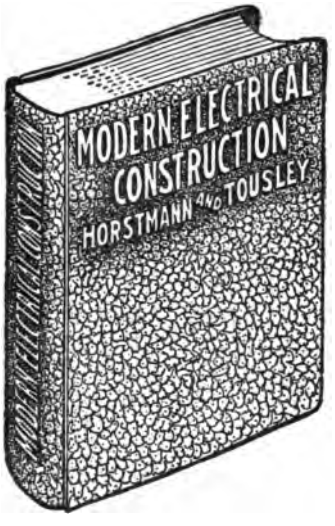

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